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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

INCLUDING THE

PROGRAMME OF THE

1958 WINTER MEETING IN THE WEST

AT THE

UNIVERSITY OF CALIFORNIA AT LOS ANGELES

December 29, 30, and 31

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BULLETIN

OF THE

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1958 Winter Meeting in the West, University of California at Los Angeles, December 29–31, 1958

THE **1958 winter meeting on the Pacific Coast** will be held on the campus of the University of California, Los Angeles 24, California, on Monday, Tuesday, and Wednesday, **December 29, 30, and 31,** 1958. The sessions will be held in the Chemistry Building and Franz Hall. Because of the New Year's holiday, no sessions are scheduled on Wednesday afternoon. The usual telephone and message board will be available, and there will be conference rooms set aside.

Hotel accommodations within walking distance of the campus are the Claremont Hotel (from $4 single, $7 double, $5 twin beds), and the Dracker Hotel (from $5 single, $6 double, $6 twin beds). The following motor hotels, located on Wilshire Boulevard, Los Angeles 24, are close to the Village and the campus: Hotel Westwood Plaza (from $6 single, $8 double, $8 twin beds), Ritz Wilshire Motor Hotel (from $5 single, $7 double, $7 twin beds), Tropic Palms Hotel (from $5 single, $6 double), Westwood Inn Motor Hotel (from $9 single, $12 twin beds). There are also the Bel-Air Hotel on Stone Canyon Road (from $15.50 single, $18.50 double), Bel Air Sands on Sunset Boulevard (from $13 single, $16 double), Miramar Hotel in Santa Monica (from $8 single, $13 twin), Hilton Hotel in Beverly Hills (from $13 single, $17 twin beds), Surf Rider Inn, Ocean Avenue, Santa Monica (from $8 single, $8 double).

Since the period between the holidays is a very busy season for the hotels and motels, reservations should be made early, *at least one month before the meeting.* Requests for reservations should be sent directly to the hotel or motel.

The **cafeteria** in Kerckhoff Hall will be open for lunch during the first two days of the meeting. This will be a great convenience for the members and, since the Society will be guaranteeing a minimum number of diners, it is urged that this restaurant be used if possible.

Registration, including information concerning accommodations, the banquet, side trips, and other information, will be at the desk in the lobby of the Chemistry Building. The usual charge of $1.00 will be in force. The desk will be staffed from 8 A.M. to 5 P.M., during the meeting days. Professor J. R. Richardson is the chairman of the local committee, and requests for special information should be addressed to him.

Tickets for the **banquet** of the Society will be sold at the registration desk. The price is $4 per person. The dinner will be held at 7:30 P.M. Tuesday evening at the Miramar Hotel in Santa Monica, a 15-minute drive or bus ride from the University. Those going to the banquet are urged to send in their reservations on the form for this purpose included in this Bulletin, and they will be held until 12 noon on Tuesday. This is important, because the dinner was oversubscribed at some of the recent meetings on the West Coast. We are fortunate in that our principal speaker will be Professor H. C. Urey, of the University of California, and the title of his talk will be "Some Comments on Present Day Physics." Professor J. Beams, President of the Society, will preside. Chancellor R. B. Allen, of the Los Angeles campus of the University of California, will greet the Society at the banquet.

The program consists of **123 contributed papers and 35 invited papers.** The program was arranged with the aid of a committee consisting of J. R. Richardson, H. Ticho, B. Wright, D. Saxon, and N. Oleson. A very special feature of this program involves sessions E and H. These sessions were designed with an audience of interested experts in mind, and the papers are expected to be very technical and detailed. They will not have the review character representative of the usual invited papers on the program of the Society. If this program is successful, it will be repeated for

this and other subjects at future meetings in the hope that the open attendance afforded by American Physical Society meetings can be more useful to experts in given fields than the closed conferences that have become widespread.

Post-deadline papers of sufficient importance to warrant their inclusion in a special supplementary program will be considered by the Local Secretary if the abstracts are received no later than Tuesday, December 23, at the office of the Local Secretary for the Pacific Coast (see address below). These papers will be presented following sessions that will be designated on a blackboard near the registration desk.

Errata will be published in a later issue of this Bulletin if received not later than Monday, January 12, at the office of Miss Ruth Bryans, American Institute of Physics, 335 East 45th Street, New York 17, New York. Do not send your abstract defaced with corrections: write out the corrections in the form "Instead of . . . read. . . ." Do not add anything. Errata are not published either for introducing new data, or for restoring material that was cut out because the abstract was too long.

W. A. NIERENBERG
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Berkeley 4, California

EPITOME OF THE 1958 WINTER MEETING IN THE WEST AT THE UNIVERSITY OF CALIFORNIA AT LOS ANGELES

(Personal names are those of invited speakers.)

Monday Morning

10:00 A. Intermediate-energy nuclear physics; Bischsel, Brolley, Eisberg, Cohen. Chemistry 2250.

10:00 B. Solid-state physics I; Kittel. Franz Hall 104.

10:00 C. High-energy physics I. Chemistry 2276.

Monday Afternoon

1:30 D. Controlled fusion; Post, Tuck, Gottlieb, Colgate, Barnett. Chemistry 2250.

2:00 E. Theoretical physics. Chemistry 2276.

1:30 F. Low-energy nuclear physics. Franz Hall 104.

Tuesday Morning

9:30 G. Symposium on high-energy physics I; Tollestrup, Steinberger, Crowe, Hilton, Gell-Mann, Cool. Chemistry 2250.

9:30 H. Solid-state physics II; Kaiser. Franz Hall 104.

10:00 I. Plasma physics and other topics. Chemistry 2276.

Tuesday Afternoon

1:30 J. Symposium on high-energy physics II. Stork, Whitehead, Kerth, Schluter, Murray, Dalitz, Walker. Chemistry 2250.

2:00 K. Solid-state physics III; White. Franz Hall 104.

2:00 L. Resonance physics and other topics. Chemistry 2276.

Tuesday Evening

7:30 Banquet of the American Physical Society; Urey. Miramar Hotel.

Wednesday Morning

10:00 M. Theoretical physics; Finkelstein, Drell, Chew, Wightman. Franz Hall 104.

9:30 N. Low-energy nuclear physics. Chemistry 2276.

9:30 O. Electron physics; Geballe, Fisher, Weissler, Gould, Bernstein. Chemistry 2250.

9:30 P. High-energy physics II. Chemistry 2224.

PROGRAMME

MONDAY MORNING AT 10:00

Chemistry 2250

(BYRON T. WRIGHT presiding)

Invited Papers on Intermediate-Energy Nuclear Physics

A1. Stopping Power and Shell Corrections Derived from Range-Energy Measurements of Protons. HANS BICHSEL, *University of Washington.* (30 min.)

A2. Interactions between Light Nuclei at Intermediate Energies. JOHN BROLLEY, *Los Alamos Scientific Laboratory.* (30 min.)

A3. Measurement of Proton Total Reaction Cross Sections at Intermediate Energies. R. M. EISBERG, *University of Minnesota.* (30 min.)

A4. Medium Energy Nuclear Reactions in Heavy Elements. BERNARD L. COHEN, *University of Pittsburgh.* (30 min.)

MONDAY MORNING AT 10:00

Franz Hall 104

(J. R. PELLAM presiding)

Solid-State Physics I

Invited Paper

B1. Spin Waves in Ferromagnets. C. KITTEL, *University of California, Berkeley.* (30 min.)

Contributed Papers

B2. Specific Heat of Liquid He^3 under Pressure below 1°K.* D. F. BREWER, A. K. SREEDHAR, AND J. G. DAUNT, *The Ohio State University.*—Our measurements of the specific heat of liquid He^3 at the saturated vapor pressure[1] have been extended to pressures up to the melting point, in the temperature range 0.12°K−0.6°K. The apparatus was essentially the same except for the calorimeter, whose surface area was considerably increased to overcome the increasing effect of the thermal boundary resistance. At the higher temperatures, the specific heat decreases monotonically with increasing pressure, in the normal manner. At 0.16°K, a cross-over in the specific heat isobars takes place, and at lower temperatures $(\partial C_p/\partial p)_T$ is positive. This is in general agreement with the theory of Brueckner and Gammel,[2] but the magnitude $(\partial C_p/\partial p)_T$ is less than indicated by the theory. At the lowest temperature the specific heat under pressure is still not linear in the temperature, in contrast to the vapor pressure specific heat. Although the entropies cannot therefore be calculated, it seems probable that $(\partial S/\partial p)_T$ is also positive at the lower temperatures, so that the expansion coefficient α is negative, as expected. The slope $(\partial\alpha/\partial T)_p$ must also be negative below 0.16°K, since the minimum in α must occur at a higher temperature than that where $(\partial C/\partial p)_T$ is zero.

* This work was supported by a Grant-in-Aid from the National Science Foundation.

[1] Brewer, Sreedhar, Kramers, and Daunt, Phys. Rev. 110, 282 (1958).

[2] K. A. Brueckner and J. L. Gammel, Symposium on He^3, The Ohio State University (August, 1957).

B3. Extension of the Ferrell-Glover Sum Rule on Superconducting Penetration Depths.* M. TINKHAM, *University of California, Berkeley.*—The Ferrell-Glover[1] sum rule relating supercurrent phenomena to the energy gap in superconductors is extended to take explicit account of the frequency dependence of the normal state conductivity and of the nonlocal relation between the current density and the electric field. It can be seen that in any energy gap model the superconducting penetration depth must increase when the electronic mean free path is decreased (by impurities, imperfections, or surface scattering) below a characteristic length ξ_0, defined as in Pippard's theory.[2] A useful criterion for theories of the penetration depth in ideal samples is also obtained.

* Research supported by the Office of Naval Research, the National Science Foundation, and the Alfred P. Sloan Foundation.

[1] R. A. Ferrell and R. E. Glover, III, Phys. Rev. 109, 1398 (1958).

[2] A. B. Pippard, Proc. Roy. Soc. (London) A216, 547 (1953).

B4. Far Infrared Energy Gap Measurements in Bulk Superconductors.* P. L. RICHARDS† AND M. TINKHAM, *University of California, Berkeley.*—Using far infrared techniques, we have investigated the onset of absorption in bulk superconductors for $T \ll T_c$ over the quantum energy range of 1 to 13 kT_c for lead and 2 to 18 kT_c for tin. This range corresponds to wavelengths from ~0.15 to 2 mm. The measurements show a sharp absorption edge in pure superconductors that may be interpreted in terms of electron excitations across an energy gap. We find widths of the energy gap at absolute zero of $4.1\pm0.2kT_c$ for lead and $3.4\pm0.3kT_c$ for tin.[1] These results indicate a departure from the law of corresponding states. Similar measurements on superconducting alloys indicate that the onset of absorption is less sharp than in pure metals.

* Supported in part by the Office of Naval Research, the National Science Foundation, and the Alfred P. Sloan Foundation.

† National Science Foundation Predoctoral Fellow.

[1] P. L. Richards and M. Tinkham, Phys. Rev. Letters (to be published).

B5. Low-Temperature Absorption Spectra of U^{+4} Ions in Crystals.* DONALD J. YOUNG† AND ROBERT A. SATTEN, *University of California at Los Angeles*, AND DIETER M. GRUEN, *Argonne National Laboratory*.—The spectrum of U^{+4} ions in two mixed salts, Cs_2UCl_6 and $[(CH_3)_4N]_2UCl_6$ was observed down to liquid helium temperature, and energy levels were deduced. A comparison of the spectra of the two salts shows that the crystalline Stark splitting is remarkably similar even though this splitting is much larger than in the trivalent rare earths. The similarity of the Stark splittings shows that almost the entire crystalline field splitting is due to the octahedrally arranged Cl^- ions in the $UCl_6^=$ complex, since the two crystal structures are otherwise not the same, one being trigonal and the other cubic. The pure electronic transitions themselves are not observed but always electronic transitions with simultaneous change in the vibrational state. This proves that the transitions are electric dipole since the U ion is at a center of inversion. The superimposed vibrational levels are different in the two salts except for three frequencies corresponding to the $UCl_6^=$ internal vibrations which the salts have in common. Further analysis of the spectrum with the aid of energy level calculations and infrared data will be reported at a later date.

* Supported in part by the Office of Ordnance Research and U. S. Atomic Energy Commission.
† Now at I.B.M., Santa Monica, California.

B6. Domain Wall Dynamics in the Superconducting Intermediate State.* DONALD FELDMAN AND RICHARD CONLEY LA FORCE, *University of California, Berkeley*.—We have investigated the dynamics of domain wall motion in the superconducting intermediate state for lead and tin samples in the form of either rods, diameter 140 μ, or small particles, diameter 1–10 μ. The susceptibility, χ, of the samples was measured as a function of applied magnetic field, H, by placing the sample in an rf oscillator tank coil and observing the frequency shift *vs* H. The same arrangement was used to determine $d\chi/dH$, but in the case 0.1 to 1% of the applied magnetic field was modulated at a frequency f between 10 cps and 50 kc in order to produce the derivative. The $d\chi/dH$ *vs* H curve has a maximum value where χ *vs* H has maximum slope. However hysteresis effects are observed in $d\chi/dH$ *vs* H which are not observed in χ *vs* H. Moreover a second maximum in $d\chi/dH$ for lead is observed above the critical field. The amplitude of the maximum in the $d\chi/dH$ *vs* H curve below the critical field is a function of modulation frequency, f, and is proportional to $1/f^{\frac{1}{2}}$ for large f. This latter behavior is understandable on the basis of a theory of eddy current damped domain wall motion.

* Supported in part by the Office of Naval Research, the Signal Corps, the National Security Agency, and the Air Force Office of Scientific Research.

B7. Antiferromagnetic Magnon Dispersion Law and Bloch Wall Energies in Ferromagnets and Antiferromagnets.* R. ORBACH,† *University of California, Berkeley*.—The exact eigenstates of the exchange Hamiltonian are found for short chains of 4, 6, 8, and 10 atoms of spin $\frac{1}{2}$.[1] A linear dispersion law for magnons in an antiferromagnet is exhibited by the energy spectrum. Rotation operators are applied to the exact ferromagnetic and antiferromagnetic ground states to give semiclassical states simulating 360° Bloch walls. These states are projected upon the exact eigenvectors of the exchange Hamiltonian. The wall energies are computed, and it is shown that the $S=0$ and $S=1$ states are most important. The periodic boundary conditions are then removed, and the ends of the chain held fixed, both parallel or antiparallel. The energy of the 180° Bloch wall is computed and compared with the classical result. It is found that the semiclassical ferromagnetic wall is a good approximation to the exact wall. The energy of the semiclassical antiferromagnetic wall is not a very good approximation to the exact wall energy, but the semiclassical energy appears to have the correct dependence on the wall thickness.

* This research was supported in part by the Office of Naval Research, the Signal Corps, the Air Force Office of Scientific Research, and the National Security Agency.
† National Science Foundation Predoctoral Fellow.
[1] The complete list of eigenvectors and eigenvalues will be available in the author's thesis, Berkeley, 1959.

B8. Disordered Regions in *n*-Type Germanium Bombarded by Fast Neutrons. B. R. GOSSICK, *Arizona State College*, AND J. H. CRAWFORD, JR., *Oak Ridge National Laboratory*.*—The nature of the potential well produced by a disordered region (thermal spike) in neutron irradiated n-type germanium is estimated. It is concluded that, in representative cases, a space charge region forms outside the disordered region (assumed to be p-type) which is greater in extent than the disordered region by as much as two orders of magnitude. The wells, surrounding a disordered region, should be white to electrons, but not necessarily black to holes. Some effects of disordered regions, e.g., (a) scattering of conduction electrons, (b) absorption of holes, and (c) polarizability will be discussed.

* Oak Ridge National Laboratory is operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.

B9. Measurements of the Dember Potential in Bulk Germanium. L. STUBBE* AND B. R. GOSSICK,* *Motorola, Inc.*—The potential difference across a semiconducting sample, which arises from the Dember[1] field, *viz.*, from a gradient of excess carrier density, and which depends on the mobilities of holes and electrons being unequal, has been observed. Measurements of this voltage and photoconductivity permit a determination of the ratio (mobility of electrons/mobility of holes) by a relation given by van Roosbroeck.[2] The ratio 2.1 was obtained for germanium, which agrees with the findings of Prince.[3]

* Now at Arizona State College, Tempe, Arizona.
[1] H. Dember, Physik Z. 32, 554 (1931).
[2] W. van Roosbroeck, Phys. Rev. 91, 282 (1953); Bell System Tech. J. 29, 560 (1950).
[3] M. B. Prince, Phys. Rev. 92, 681 (1953).

B10. Lifetimes and Trapping of Carriers in Semiconducting Diamond.* J. H. WAYLAND AND W. J. LEIVO, *Oklahoma State University*.—Lifetimes and trapping of carriers in semiconducting diamond have been studied from the response and decay times of photoconductivity. The gem quality diamond investigated has a resistivity of 3.5×10^8 ohm cm and is photoconducting in the visible region. Hall measurements show p-type conductivity with a hole mobility of 1300 cm²/volt sec. From the rise time of the photocurrent, using light in the fundamental absorption region, a lifetime of 9μsec was obtained. This is possibly largely independent of trapping. From decay curves, lifetimes, which include trapping, of 125μsec, 800μsec, 0.25 sec, 12 min, and 84 min were obtained. Using visible light, the response and decay time of the photocurrent is dependent upon the wavelength of the exciting radiation because several intermediate energy levels are present in this region. Various recombination times obtained include 20 msec, 30 sec, 6 min, and 39 min.

* This research was supported by the U. S. Air Force Office of Scientific Research of the Air Research and Development Command.

B11. Forbidden Functions in Crystals. PETER E. KAUS,* *RCA Laboratories*.—The usual boundary condition for Bloch functions of the form $\Psi_n(\mathbf{k},\mathbf{r})=e^{i\mathbf{k}\cdot\mathbf{r}}u_n(\mathbf{k},\mathbf{r})$, that $\mathbf{k}$ be real, is relaxed, and all the solutions to the Schrödinger equation are considered. The energy $E(\mathbf{k})$ then may be considered as the real part of an analytic function of the real and imaginary part of $\mathbf{k}$. The forbidden (complex $\mathbf{k}$) solutions exhibit real damping, violating the boundary conditions of a pure, infinite crystal. By a suitable choice of Green's functions the forbidden

solutions can be expressed in terms of the allowed and classified according to whether they damp away from a point, a line, or a surface. The functions represent the asymptotic forms of all localized wave functions in a crystal and have the proper localization for impurity wave functions and surface state functions. Approximations of the forbidden functions, based on information at the band edges, can be formulated and yield qualitative information on the shape and localization of impurity wave functions.

* Present address: University of Southern California.

MONDAY MORNING AT 10:00

Chemistry 2276

(R. F. CHRISTY presiding)

High-Energy Physics I

C1. Gas Cherenkov Counters for High-Energy Particle Detection.* VICTOR PEREZ-MENDEZ, JOHN H. ATKINSON, AND WILMOT N. HESS, *University of California, Berkeley.*—A number of gas-filled Cherenkov counters have been built for use as threshold detectors for particles with β ranging from 0.986 to 0.999. The filling gases used have been CCl_3F_2 and SF_6, both of which have relatively high indices of refraction and are transparent in the visible and ultraviolet. The counter consists of a steel cylinder 6 feet long and 4 inches in diameter, filled with gas. At the rear end a plane front-surface mirror reflects the light at 90 degrees to the incident direction up to the photomultiplier, a 16-stage RCA C 7232A. The performance of the counter was checked in a 3.0 ± 0.1-Bev pion beam to determine the slope of the threshold sensitivity curve so that a counter of this type can be used as a detector for elastic scattering experiments. Two of these counters have been in use during the past year as threshold detectors for high-energy pions produced by neutrons in a Bevatron experiment.

* Work done under the auspices of the U. S. Atomic Energy Commission.

C2. Interaction of Low-Energy K^+ Mesons with Nuclei. J. GRANT AND DONALD H. STORK, *University of California, Los Angeles.**—The interaction cross section of K^+ mesons at low energies (40–60 Mev) has been computed from the energy dependence of the mean free path in nuclear matter and the real part of the potential. These have been determined by means of the phase shifts deduced at 125 Mev[1] with the usual momentum variation and through the use of the Sternheimer factor for exclusion-principle effects. A square-well model with a 25-Mev fermi energy predicts too small a cross section at these energies. We have therefore used the diffuse-surface real potential and taken a strict statistical-model correlation between Fermi-energy and the Stanford radial density dependence.[2] Although lacking in physical justification, this technique has the desired effect of considerably relaxing the suppression of final nucleon states for surface interactions. The resulting cross sections computed by averaging the attenuation for classical trajectories (also not entirely justified) are in good agreement with the available experimental data. While detailed agreement may be fortuitous we conclude that a significant surface interaction contributes to the low-energy K^+-meson reaction cross sections.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Price, Stork, and Ticho, Phys. Rev. Letters 1, 212 (1958).
[2] Hahn, Ravenhall, and Hofstadter, Phys. Rev. 101, 1131 (1956).

C3. On the Interactions of 200 to 300-Mev K^+ Mesons with Emulsion Nuclei. D. H. STORK, E. HELMY, AND D. J. PROWSE, *University of California, Los Angeles.**—Over 100 meters of K^+-meson track length in the energy interval 200–300 Mev have now been followed at Los Angeles. The results confirm the tendencies of the preliminary data which have been reported previously.[1] The K−H cross section appears sensibly constant with energy at about 16 mb/steradian. The charge-exchange cross section has increased significantly over that obtained at lower energies; this indicates that the scattering in the $T=0$ state has increased. The differential cross section for K^+-neutron scattering has been deduced from the data and it indicates the presence of p-wave scattering in the $T=0$ state. A very preliminary phase-shift analysis neglecting any $T=1$ p-wave contributions gives the following values; $\delta_0{}^1=-35°$, $\delta_0{}^0=-8°$ and the $\delta_1{}^0$ and $\delta_1{}^1$ both probably positive and $\lesssim 25°$. A detailed phase-shift analysis patterned after that of Price *et al.*[2] is in progress and results will be discussed.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Helmy, Mulvey, Prowse, and Stork, Grilli, Guerriero, Merlin, O'Friel, Evans, Hassan, Nagpaul, Shafi, and Wataghin, Bull. Am. Phys. Soc. Ser. II, 3, 163 (1958).
[2] Price, Stork, and Ticho, Phys. Rev. Letters 1, 212 (1958).

C4. Elastic Scattering of 250-Mev K^+ Mesons from Emulsion Nuclei. M. A. MELKANOFF, E. HELMY, D. J. PROWSE, AND D. H. STORK, *University of California, Los Angeles.**—Over 100 meters of K^+-meson track length in the energy interval 200–300 Mev have been searched for elastic scattering events with a projected angle of scatter in the emulsion plane of $\geq 2°$. From the distribution in scattering angles, the differential cross section per average emulsion nucleus has been obtained. A diffuse-surface optical model analysis of these results is in progress. In this study the four parameters: R_0, the radius parameter; a, the surface thickness; V, the real part of the potential; and W, the imaginary part of the potential, are varied and the goodness of fit determined, after averaging over emulsion nuclei and beam energy, by the χ^2 test. For $R_0=1.07$ fermi and $a=0.57$ fermi, preliminary results indicate a satisfactory fit with W approximately -22 Mev (it is substantially fixed by the average reaction cross section) and with V approximately the same or slightly lower than that found in the energy region 125–150 Mev.[1,2]

* Partly assisted by the U. S. Atomic Energy Commission.
[1] Igo, Ravenhall, Tiemann, Chupp, G. Goldhaber, S. Goldhaber, Lannutti, and Thaler, Phys. Rev. 109, 2133 (1958).
[2] Melkanoff, Price, Stork, and Ticho, Phys. Rev. (to be published).

C5. Analysis of K^- Meson Elastic Scattering from Emulsion Nuclei. D. J. PROWSE, M. A. MELKANOFF, AND D. H. STORK, *University of California, Los Angeles.**—In an attempt to get some definitive information on the sign of the K^--meson nuclear potential, the published experimental data on the elastic scattering from emulsion nuclei have been re-examined. A previous analysis[1] has used approximate methods and assumed that the imaginary part of the potential is small. Within these limits the potential appeared to be positive. It is now known that the imaginary potential is not small. Exact solutions for elastic scattering from a diffuse-surface complex well have been obtained for various well parameters.

Comparison of the resulting cross sections with the experimental data is in progress. The imaginary part of the potential is essentially fixed by the reaction cross section as in the K^+-meson case and preliminary indications are that the scattering is rather insensitive to the magnitude of V.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Bhowmik, Evans, Falla, Fowler, Kamal, and Prowse, Proc. Intern. Conf. on Mesons and Recently Discovered Particles, Padua-Venice II, 45 (1957).

C6. Collisions of Λ^0 and Anti-Λ^0 Hyperons with Nucleons at Intermediate Energies. J. S. KOVACS AND D. B. LICHTENBERG, *Michigan State University.*—A calculation is made of Λ^0-nucleon (ΛN) scattering cross section and the $\bar{\Lambda}N$ scattering and annihilation cross sections at energies up to 150 Mev in the laboratory system. The ΛN potential, which is taken of exponential form outside a hard core, is adjusted to fit the binding energy of the Λ^0 in hyperfragments. Calculations are made both with and without an additional spin-orbit interaction of the type used by Signell and Marshak.[1] The same potential is used in the $\bar{\Lambda}N$ case, except that the hard core is replaced by a black absorptive hold, after the work of Ball and Chew.[2] It is recognized that at least one K meson must be emitted in a $\bar{\Lambda}N$ annihilation process, so that the radius of the black hole (if indeed a black hole exists) is not necessarily the same as in $\bar{N}N$ annihilation. However, Ball and Chew have shown that the radius of the black hole is not important at intermediate energy. A comparison of results, with and without a spin-orbit potential, will be given. The identity of the $\bar{\Lambda}N$ and ΛN potential outside the hard core follows from the assumption that this portion of the potential arises chiefly from the exchange of two pions.

[1] P. S. Signell and R. E. Marshak, Phys. Rev. 109, 1219 (1958).
[2] J. S. Ball and G. F. Chew, Phys. Rev. 109, 1385 (1958).

C7. Radiative Capture of Orbital K^- Mesons by Nuclei.* GRAHAM FRYE, *University of California, Berkeley.*—We discuss the radiative transition of K^- mesons in atomic orbitals from a state (n,l) to a state $(n',l-1)$ on the assumption that nuclear capture is much more likely from the latter state. The x-radiation may occur together with the orbital K^--meson capture as part of a two-step process. Then the energy released by the capture is shared with the proton, giving it a continuous spectrum with typical resonance peaks corresponding to the usual x-ray lines. The theory[1] for radiative capture of K electrons is applied in detail to this problem. The photon spectrum and the total transition probabilities for radiative capture from $l=1, 2, 3\cdots$ states are estimated. In radiative capture from the $2P$ state, for instance, two percent of the photons have an energy greater than twice the $1S$-state binding energy.

* Supported in part by the Air Force Office of Scientific Research.
[1] R. J. Glauber and P. C. Martin, Phys. Rev. 104, 158 (1956).

C8. Coulomb Disintegration of Hyperfragments. H. NEUMANN AND H. S. VALK, *University of Oregon.*—Recent studies[1] on the binding energies of hypernuclei indicate that many of these structures exist as a loosely bound aggregate of a Λ_0 and a nuclear core. If the Λ_0-nucleus interaction is described by a square-well potential, an estimate of the probability for hyperfragment disintegration in nuclear Coulomb fields can be made on the basis of earlier theories.[2,3] The use of such a procedure for ${}_\Lambda\mathrm{He}^5$ indicates that at the presently available kinetic energies these events will be highly improbable.

[1] R. H. Dalitz, Mid-West Conference on Theoretical Physics (1957), Iowa; Repts. Progr. in Phys. 20, 163 (1957).
[2] S. Dancoff, Phys. Rev. 72, 1017 (1947).
[3] V. Mamasakhlisov and G. Chilashvili, Zhur. Eksptl. i Teoret. Fiz. 32, 806 (1957).

C9. Ξ^- Production by 5-Bev/c Negative Pions.* WILLIAM B. FOWLER, WILSON M. POWELL, AND JOHN I. SHONLE, *University of California, Berkeley.*—This paper reports the production of two negative cascade particles at the Bevatron. A 30-in. propane bubble chamber was exposed to a beam of negative pions with a momentum of 5.3 ± 0.3 Bev/c. Approximately 34 000 pictures were taken. Two negative cascades were found and identified with a high degree of confidence. One cascade particle was produced in a six-prong carbon star with no identifiable associated strange particles. It has a Q of 48.0 ± 10.5 Mev, and a proper lifetime of 1.90×10^{-10} sec. The other cascade particle was the only charged particle from its carbon star and had one visible θ_1^0 decay associated with it. The Q in this case was 56.1 ± 9.2 Mev and the proper lifetime was 4.77×10^{-10} sec. The Q values given are adjusted fits that constrain the Q values of the Λ's to 37 Mev and to transverse momentum balance, and the error is a standard deviation. Ionization information is not very definitive in these pictures, but is compatible with the particle assignments in both cases. Both cascades were produced in the backward hemisphere in the center-of-momentum system. The production cross section is on the order of 1.5 μbarns/nucleon. Both production events are compatible with strangeness $S=-2$ for the cascade particle.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

C10. Antiproton Annihilations in Propane.* R. LANDER, L. AGNEW, T. ELIOFF, WILLIAM B. FOWLER, L. GILLY, L. OSWALD, WILSON M. POWELL, E. SEGRÈ, H. STEINER, H. WHITE, C. WIEGAND, AND T. YPSILANTIS, *University of California, Berkeley.*—The Berkeley 30-in. propane bubble chamber was exposed to a separated antiproton beam of 222-Mev kinetic energy entering the propane. The range of a stopping antiproton of this energy is 24 in. More than 400 $\bar{p}$ annihilations in flight or at rest were observed. Elastic scattering cross sections for hydrogen and carbon have been reported previously.[1] This paper reports on the annihilation events, giving cross sections for hydrogen and carbon within this energy interval, charged-pion multiplicities and momentum distributions, and neutral-pion multiplicity as determined from more than 100 gamma-ray conversion events within the propane. Both the carbon and hydrogen annihilation cross sections show a rapid increase with decreasing energy. Their ratio seems to be approximately constant at a value of about seven. Strange-particle production occurs in at least 2% of the annihilations.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] Agnew, Elioff, Fowler, Gilly, Lander, Oswald, Powell, Segrè, Steiner, White, Wiegand, and Ypsilantis, Phys. Rev. 110, 994 (1958); Phys. Rev. Letters 1, 27 (1958).

C11. Study of Nuclear Interactions in Carbon Produced by Cosmic Rays with Energies in the Region 10^{11} ev to 10^{13} ev.* LUISA F. HANSEN AND W. B. FRETTER, *University of California, Berkeley.*—A cloud chamber in a magnetic field has been used in the analysis of high-energy nuclear interactions produced in carbon by cosmic rays at sea level. The particles produced in the interactions were identified with reasonable certainty from their momenta and their ionization in the relativistic region up to momenta of 20 Bev/c. Forty interactions containing 3 or more penetrating particles have been analyzed, using momentum, ionization, and angle measurements in the cloud chamber. Results have been obtained on the angular and energy distribution of pions and strange particles, and the multiplicities of pions and strange particles. The average multiplicity of charged pions is 3.4, which is considerably smaller than that obtained in emulsions in this energy range. This may be an indication that interactions in carbon are more nearly nucleon-nucleon collisions than they are in photographic emulsions. The total number of particles observed in

these 40 showers was 135 charged pions, 14 K particles, 33 protons, and 2 hyperons. Presence of π^0 mesons in the showers can often be inferred from the fact that high-energy electrons can be identified. Fifty additional showers containing only two penetrating particles will also be discussed.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

C12. Neutron Cross-Section Measurements at 4.5 Bev.* JOHN H. ATKINSON, WILMOT N. HESS, VICTOR PEREZ-MENDEZ, AND ROGER W. WALLACE, *University of California, Berkeley.*—Attenuation cross sections for high-energy neutrons in lead, carbon, copper, and liquid hydrogen are being measures at the Bevatron with a counter telescope. Charged pions, produced in a beryllium or aluminum converter, are detected by a telescope of three scintillation counters and a gas Cherenkov counter. The gas pressure in the Cherenkov counter determines the detection threshold for pions and hence for the incident neutrons. A lead filter and a sweeping magnet eliminate electrons produced from π^0-meson decay. We used an effective neutron threshold of about 3 Bev. The cross sections of Pb and C were measured as a function of geometry, with the good-geometry measurements giving, for lead, $\theta/2=0.184°$, $\sigma_t=2.32\pm0.13$ barns; and for carbon, $\theta/2=0.209°$, $\sigma_t=354\pm11$ μb. The poor-geometry limit gives, for lead, $\theta/2=4°$, $\sigma_a=1.66\pm0.09$ barns; and for carbon, $\theta/2=7°$, $\sigma_a=218\pm8$ μb. Good-geometry measurements with copper give $\sigma_t=1093\pm30$ μb. Poor-geometry measurements with copper and good-geometry measurements with liquid hydrogen are under way. Small geometric corrections are also being made on the data.

* Work done under the auspices of the U. S. Atomic Energy Commission.

MONDAY AFTERNOON AT 1:30

Chemistry 2250

(J. R. RICHARDSON presiding)

Invited Papers on Controlled Fusion

D1. High-Temperature Plasma Research with the Magnetic Mirror Machine. RICHARD F. POST, *University of California, Livermore.* (30 min.)

D2. The Future of the Pinch. JAMES L. TUCK, *Los Alamos Scientific Laboratory.* (30 min.)

D3. Controlled Fusion Research Using the Stellerator. MELVIN B. GOTTLIEB, *James Forrestal Research Laboratories.* (30 min.)

D4. Implications of Nonadiabatic Electron Loss in the Stabilized Pinch. STIRLING A. COLGATE, *University of California, Livermore.* (30 min.)

D5. Controlled Fusion Research with DCX. CLARENCE F. BARNETT, *Oak Ridge National Laboratory.* (30 min.)

MONDAY AFTERNOON AT 2:00

Chemistry 2276

(S. A. MOSZKOWSKI presiding)

Theoretical Physics

E1. Application of a Rearranged Cluster Series to Hard Core Fermi Systems. AARON TEMKIN, *Naval Research Laboratory.*—An explicit form of the cluster expansion of the ground state energy corresponding to a Jastrow[1] trial function has recently been obtained by Aviles[2] and others.[3] We have applied these formulas to the low density, hard core Fermi gas. One is led quite naturally to a rearrangement of the series as an expansion in terms of the Fermi momentum. This series is of the same type as the recently calculated exact series.[4] The rearrangement can also be extended to the problem of nuclear matter, where the method results in a considerable simplification of the straight cluster development.[5] The coefficients are uncomplicated algebraic functions of the variational and nuclear parameters. Our numerical results are thus readily obtained, and they will be compared to those of Iwamoto and Yamada.[5]

[1] R. Jastrow, Phys. Rev. **98**, 1475 (1955).
[2] J. Aviles (to be published).
[3] C. D. Hartogh and H. A. Tolhoek, Physica **24**, 721 (1958) and two preprints (to be published).
[4] T. D. Lee and C. N. Yang, Phys. Rev. **105**, 1119 (1957); P. Martin and C. de Dominicis, Phys. Rev. **105**, 1418 (1957).
[5] F. Iwamoto and M. Yamada, Progr. Theoret. Phys. (Kyoto) **19**, 345 (1957).

E2. Spectral Representations of General Green's Functions in Perturbation Theory. J. D. BJORKEN, *Stanford University.*—Using the techniques of Nambu,[1] the analytic properties of a general Feynman diagram are displayed. The only singularities as a function of the scalars formed from the external momenta occur as poles or branch cuts along the real axis. By means of an analogy with electrical circuit theory and a variational argument, it is possible to locate the branch points. One finds that singularities exist for only those values of the external momenta such that the Feynman diagram may be decomposed into nonsingular portions connected by lines all of which are "real," that is, for which $p_i^2=m_i^2$. The vertex operator is discussed and the results of Nambu[2] and Karplus *et al.*[3] are rederived in an elementary way.

[1] Y. Nambu, Nuovo Cimento **6**, 1064 (1957).
[2] Y. Nambu, Nuovo Cimento **9**, 619 (1958).
[3] Karplus, Sommerfield, and Wichmann, Phys. Rev. **111**, 1187 (1958).

E3. Alternative Method of Quantization. JOHN A. CRAWFORD, *University of California, Berkeley.*—The renormalizable $[\mathrm{Tr}(M^\dagger M)<\infty]$ linear operators M in Hilbert space (H) form a Hilbert space (H'), with definite metric. The Hilbert

space of physics is assumed to be H' instead of H. States and observables are then associated with vectors and operators in H' in the familiar manner. The supplementary condition $M=M^{\dagger}$ is imposed upon the states, which can be either "pure" or "mixed." This method of quantization leads automatically to the introduction of new observables. In particular, for systems with a classical analog, there exist mutually commuting (classical) canonical variables (q,p) which can serve as the basis for a representation. The "wave function" in this case is real and the (non-negative definite) distribution in the corresponding classical phase space determines the state of the system. For boson fields interacting only with external sources or fields, these canonical variables satisfy the same (deterministic) equations of motion as in the unquantized theory. Thus, classical relativistic fields are not eliminated by the process of quantization. All the predictions of quantum theory are identically reproduced and no new results are obtained.

E4. Accidental Degeneracy of the Two-Dimensional Isotropic Harmonic Oscillator. HAROLD V. MCINTOSH, *RIAS, Inc.*—Schwinger[1] has given an elegant derivation of many of the properties of angular momentum. However, his discussion has been phrased in the language of second-quantized field theory. By using the theory of accidental degeneracy described by Hill,[2] it is possible to give a group-theoretical derivation of his results. The consequence is more complete insight into both the theory of angular momentum and the theory of accidental degeneracy. In addition, the ladder operators of Infeld and Hull[3] pertaining to the spherical harmonics and rotational matrix elements are obtained directly in terms of elements of the Lie algebra of the rotation group.

[1] J. Schwinger, "On angular momentum," NYO-3071, Office of Technical Services, Department of Commerce, Washington D. C. (1952).
[2] E. L. Hill, "Seminar on the theory of quantum mechanics," University of Minnesota (1954) (unpublished).
[3] L. Infeld and T. E. Hull, Revs. Modern Phys. 23, 21–68 (1951).

E5. Radiative Corrections to the Hyperfine Structure in the 1S and 2S States of Hydrogen.* CHARLES SCHWARTZ, *Stanford University.*—Mittleman[1] has recently given an account, according to the relativistic quantum electrodynamics, of the ratio of the hyperfine-structure separations in the $1S$ and $2S$ states of hydrogen. His result, proportional to α^3, appears to be in disagreement with the experimental value. Working in analogy with Bethe's[2] first description of the Lamb shift in hydrogen, we have set up the non-relativistic third-order perturbation theory to describe the effect: emission and reabsorption of a transverse photon by a bound electron while interacting with the field of the nuclear magnetic moment. Divergences in this calculation are eliminated by keeping only the state-independent terms, and then cutting off the intermediate photons at $\hbar\omega=mc^2$. Comparing, where possible, with Mittleman's results, we find that he lacks a term both in the nonrelativistic sum over states and in the $\ln\alpha$ terms. While the numerical value of this nonrelativistic calculation should not be compared with the experimental value until the entire calculation is redone relativistically, our correction for the leading $\ln\alpha$ term indicates a closer agreement between theory and experiment.

* Supported in part by the U. S. Air Force through the Air Force Office of Scientific Research.
[1] M. H. Mittleman, Phys. Rev. 107, 1170 (1957).
[2] H. A. Bethe, Phys. Rev. 72, 339 (1947).

E6. Vibrational States of the H_2^+ Ion.* JOHN R. HISKES, STANLEY COHEN, AND ROBERT J. RIDELL, JR., *University of California, Berkeley.*—Interest in the hydrogen molecular ion has arisen recently as a consequence of its various uses in controlled fusion devices. The interpretation of these applications in general requires an accurate knowledge of the vibrational states of this ion. A variational calculation of the potential for the hydrogen molecular ion in the ground electronic state has been carried out for a large number of internuclear separations. In addition, first-order dynamic corrections to this potential with an expansion parameter of the ratio of the mass of the electron to that of the nucleus has been calculated and added to obtain a potential necessary for the calculation of these vibrational states.[1] Numerical calculations of the vibrational states for the $J=0$, 2, 4, and 7 rotational states have been carried out by using a high-speed computing machine (IBM 701). The eigenvalues and wave functions for these states will be presented along with a discussion of the method of obtaining the potentials.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Cohen, Judd, and Riddell "μ mesonic molecules" (submitted to Phys. Rev.).

E7. Model for Antiproton Annihilation.* LEROY F. COOK AND JOSEPH V. LEPORE, *University of California, Berkeley.*—We have developed a simple model for the treatment of multiple production processes based on the assumption that the matrix element for such a process may be written in terms of the initial and final state wave functions and some interaction operator, I, as $\int\psi_f^*I\psi_i d\tau_f d\tau_i$. The integration is extended over all particle coordinates. It is then assumed that the result of integrating over the coordinates of the initial particles is a product of simple normalized functions, I'. If these are chosen to be step functions appropriate to a spatial volume, Ω, and the final states are taken as plane waves, we obtain the Fermi statistical model, provided $kr\ll 1$ for all final particles. We are applying the model to the problem of pion production in antiproton annihilations in hydrogen by correlating it with the calculations of Ball and Chew.[1] They assign a transmission coefficient of unity or zero to each partial wave, JM, in the initial state. Accordingly we take the final state as $\Phi_J{}^M{}_\pi j_l(kr)$, assume that we have $I'=\Phi_J{}^M{}_\pi F(r)$, and evaluate the appropriate integrals. Only those matrix elements corresponding to a transmission coefficient of unity are considered as contributing to the pion production. We believe that this method will lead to a more reasonable value of Ω than that obtained from the Fermi model.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] G. F. Chew and J. S. Ball, Phys. Rev. 109, 1385 (1958).

E8. Determination of the Pion-Nucleon Coupling Constant from n-p Scattering.* PETER CZIFFRA AND MICHAEL J. MORAVCSIK. *University of California, Berkeley and Livermore.*—The proposal of Chew[1] involving analytic continuation, in terms of scattering angle, of nucleon-nucleon cross sections into the unphysical region has been investigated for both 90-Mev and 400-Mev n-p scattering. At 400 Mev the errors in the experimental data appear to be too large for a definite result. At 90 Mev the value obtained is $f^2=0.067$, with the error as yet undetermined. Assuming that the error is not too large, this result compares favorably with the values obtained from pion-nucleon scattering and from photoproduction.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] G. F. Chew, "A proposal for determining the pion-nucleon coupling constant from nucleon-nucleon scattering," UCRL-8283 (May, 1958).

E9. Nucleon-Antinucleon Scattering.* JAMES S. BALL† AND JOSE R. FULCO,‡ *University of California, Berkeley.*—A possible explanation of the "large" value of the nucleon-antinucleon cross section in the intermediate energy range has been given by Ball and Chew[1] on the basis of the Yukawa interaction, with a "black central hole" to account for the annihilation. In view of the success of this model at 140 Mev, the calculations have been extended to 50 and 260 Mev. The values of annihilation, elastic-scattering, charge-exchange

cross sections, and the angular distributions for $\bar{p}$-p and $\bar{p}$-n elastic scattering are obtained. A comparison with the experimental data[3] shows reasonable agreement. The main conclusion is that no long-range annihilation interaction is required by the existing experimental facts; the ordinary pion-exchange force appears to be sufficiently attractive on the average to produce the observed annihilation cross section at intermediate energies. Finally, the parameters of an optical model potential for antinucleon interaction with complex nuclei are presented.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
† Supported in part by National Science Foundation and in part by the University of California Radiation Laboratory.
‡ Visitor from the Argentine Army.
[1] J. S. Ball and G. F. Chew, Phys. Rev. 109, 1385 (1958).
[2] For a list of experimental papers, see reference 5 of James S. Ball and Jose R. Fulco "Nucleon-antinucleon scattering," Phys. Rev. (to be published).

E10. Dispersion Relations for Classical Nonlocal Fields.* JOSEPH V. LEPORE AND ROBERT PROFET. *University of California, Berkeley.*—We have investigated the problem of assigning a measure of the degree of departure from causality of a classical nonlocal field theory from the point of view of the dispersion relations. Special attention has been given to theories of the type discussed by Pais and Uhlenbeck[1] which involve the modification of the field equations by the use of an entire function of the d'Alembertian operator and which therefore never correspond to a mass spectrum. Our procedure has been the rather trivial one of writing down the dispersion relations satisfied by the Green's functions which describe the potential due to a pulse and the analogous scattering problem and then substituting in these relations the nonlocal Green's functions which evidently do not satisfy them; the amount as a function of $\mathbf{k}$, ω by which they fail to be satisfied is then regarded as a measure of the degree of departure from causality of the theory. Since, in theories of the type studied, the form of the advanced effects is known, it is possible by the use of these models to get some idea about the significance of the dispersion relations in dealing with acausal theories. This investigation was begun with the idea of getting some insight into the nature of the corresponding quantum-mechanical problems.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] A. Pais and G. E. Uhlenbeck, Phys. Rev. 79, 145 (1950).

E11. Proposal for Determining the Electromagnetic Form Factor of the Pion.* WILLIAM R. FRAZER, *University of California, Berkeley* (introduced by D. Judd).—The possibility of measuring the electromagnetic form factor of the pion by extrapolation of the cross section for $e^-+p\to n+\pi^++e^-$ has been investigated. The method[1] is based on the existence of a pole in the electropion-production scattering amplitude as a function of the invariant momentum transfer of the nucleon. The residue of this pole is the pion form factor multiplied by a known coefficient. Since the pole lies slightly outside the physical range of the invariant momentum transfer, an extrapolation of the experimental data is required. An estimate of the behavior of the electropion-production cross section in the region important for the extrapolation has been made on the basis of the dispersion-theory calculation by Fubini, Nambu, and Wataghin.[2]

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] G. F. Chew and F. E. Low, "Unstable particles as targets in scattering experiments," UCRL-8427, August 21, 1958.
[2] Fubini, Nambu, and Wataghin, Phys. Rev. 111, 329 (1958).

E12. Possible Role of Three-Body Forces in Hypertriton.* D. B. LICHTENBERG, *Michigan State University.*—A variational calculation is made to determine some effects of 3-body forces in hypertriton. A triangular coordinate system and a one-parameter trial wave function of exponential form are used. The errors associated with this simple wave function are estimated to be of the order of 5–10%. Two different functional forms are assumed for the 3-body potential: type I, a potential depending on the distance between proton and Λ and between neutron and Λ, and type II, a potential depending on all three interparticle distances. Restrictions on the 2-body Λ-nucleon force are obtained which depend on the amount of 3-body force assumed to be present. It is found that a potential of type I is more effective than a potential of type II. Specifically, for exponential potentials of range comparable to the nucleon-nucleon potential, a potential of type II must be about four times as deep at the origin as a potential of type I to contribute about the same fraction of the potential energy of the system. It is also found that the 3-body potential (type I) must be as deep as the 2-body (exponential) potential at the origin to contribute about 15% as much to the potential energy.

* This work was done at the University of Hamburg, Germany.

E13. Evaluation of Large-Angle Potential Scattering.* W. M. BROWN AND D. S. SAXON, *University of California, Los Angeles.*—Using a modified WKB formulation, an approximation method for evaluating large-angle scatttering is developed which reduces the problem of computing the scattering amplitude from a volume integration to a simple quadrature, even for noncentral potentials. The method, which is applicable for high energies and slowly varying potentials is examined to determine its range of validity and, for potentials of sufficiently small eccentricity, is found to be accurate to order V/E. However, the results are expected to be less accurate in the neighborhood of any deep minima which may exist in the scattering cross section. The method is illustrated by application to specific examples and the results are compared to known exact results. Finally, the approximation is used to calculate an improved wave function in the interior of the potential, thereby giving an estimate of the accuracy of the usual WKB wave function.

* Supported in part by the National Science Foundation.

E14. Thomas Young's Interpretation of Diffraction as Applied to Electromagnetic Waves. J. MEIXNER, *Aachen Technical University,* AND O. LAPORTE, *University of Michigan.*—According to Thomas Young's interpretation of diffraction phenomena, the light passing a diffracting screen experiences a kind of reflection at the edge. For scalar waves this point of view can be derived rigorously from the Kirchhoff approximation as was shown by Maggi and Rubinowicz. It is shown that a corresponding derivation can be given in the case of electromagnetic waves such that the representation of the diffracted field vectors consists of the direct light calculated according to geometric objects plus an edge contribution. The calculation of the diffracted field, which in Kirchhoff's theory leads to double integrals over the aperture, can therefore, even in the electromagnetic case, be reduced to single integrals along the diffracting edge.

E15. Interaction between Right-Handed and Left-Handed Protein Helices. HERBERT JEHLE, *University of Nebraska.*—Linus Pauling and Robert B. Corey have shown that L-amino acids may form right-handed as well as left-handed α-helices as far as structural considerations are concerned. Whether both these helices occur in natural proteins is a question which has not yet been definitely settled. If both these structures exist, a highly specific interaction between right-handed and left-handed helices occurs.

MONDAY AFTERNOON AT 1:30

Franz Hall 104

(T. LAURITSEN presiding)

Low-Energy Nuclear Physics

F1. Calculation of Beta-Decay Mixing Ratios for Sc^{44} and Mn^{52}.* P. S. KELLY AND S. A. MOSZKOWSKI, *University of California, Los Angeles.*—Recent evidence indicates that the β interaction is predominantly $V-A$. The ratio $(C_A\int\sigma)/(C_V\int 1)$ has been determined for a number of allowed $J\rightarrow J$ β transitions from β-polarized γ-correlation experiments.[1] We attempted to evaluate $\int\sigma/\int 1$, especially the signs, for the decays of Sc^{44} $(f_{7/2})^4$ and Mn^{52} $(f_{7/2})^{-4}$ in j-j coupling. Various wave functions were considered, notably Gaussian-Serber exchange potential eigenfunctions. Considerable use was made of a d-5/2 shell analog. Results for $\int\sigma$ are fairly insensitive to the range of the effective interparticle forces for both nuclei. Nonzero values of $\int 1$ for these nuclei result only from charge dependent effects, of which we consider three: (i) Coulomb repulsion between f-7/2 protons; (ii) different neutron and proton radial wave functions due to Coulomb modification of the nuclear potential; (iii) slightly stronger attraction between unlike than like particles, due to electromagnetic effects.[2] For Sc^{44}, (i) is absent. We expect that (ii) is more important in Mn^{52} than in Sc^{44} since the effective internucleon forces are likely to be of shorter range in the former.

* This work supported in part by the Office of Ordnance Research.
[1] F. Boehm and A. H. Wapstra, Phys. Rev. 109, 456, 1018 (1958).
[2] L. Hulthen and M. Sugawara, *Handbuch der Physik* (Springer-Verlag, Berlin, 1957), Vol. 39, pp. 88–91.

F2. Longitudinal Polarization of the Beta Rays from Pr^{144}.* J. K. KLIWER AND J. J. KRAUSHAAR, *University of Colorado.*—Using an experimental arrangement very similar to that described by Frauenfelder *et al.*[1] the longitudinal polarization of the ground-state transition in Pr^{144} has been measured using Møller scattering. The ground state transition (2.97 Mev) is most likely 0^- to 0^+. For incident beta rays in the 0.7 to 2.8 Mev range δ was found to be in preliminary measurements -0.058 ± 0.019, where $\delta\equiv 2(C_a-C_p)/(C_p+C_a)$ and C_p and C_a are the number of coincidence counts with field in the direction and opposed to the direction of the momentum, respectively. This corresponds to a polarization of about 0.75 in a direction opposite to the momentum. The average value of v/c for the energy range is 0.95 which is within the error of the experimental value. The accuracy and limitations of this type of experiment will be discussed along more recently obtained results.

* Work supported in part by the U. S. Atomic Energy Commission.
[1] Frauenfelder, Hanson, Levine, Rossi, and DePasquali, Phys. Rev. 107, 643 (1957).

F3. Longitudinal Polarization of O^{14} Positrons.* J. B. GERHART, F. H. SCHMIDT, HANS BICHSEL, AND J. C. HOPKINS, *University of Washington.*—Seventy-two-second O^{14} undergoes positron decay via a pure Fermi transition to the well-known 2.3-Mev state of N^{14}. We have studied the positron polarization. O^{14} was produced by the $N^{14}(p,n)$ reaction on N_2 gas in the University of Washington cyclotron. The active gas was filtered to remove C^{11}, converted to water vapor, and the latter was trapped to form a concentrated O^{14} source ($\sim$5 mC). A magnetic spectrometer separated the positrons from the 2.3-Mev γ rays. The latter were focused on a plastic scintillator serving both as a detector and an annihilator. The annihilation-in-flight γ rays, circularly polarized, were scattered from the inside surface of a magnetized iron cylinder to a 3-×3-in. NaI(Tl) detector in the manner used, for example, by Boehm and Wapstra.[1] Small pulses in the plastic detector, corresponding to large energy annihilation quanta and large γ-detector pulses, were fed to a conventional fast-slow coincidence circuit. The resulting coincidence spectrum was displayed on a 20-channel pulse analyzer. Coincidence γ counts were made for each direction of the magnet field in a programed manner and normalized to the total β count. About 140 counting runs were made for each field direction. For analysis a γ-ray energy band from 600 to 1000 kev was chosen. After corrections for accidental coincidence the resulting asymmetry is $(1.94\pm0.46)\%$.

* Supported in part by the U. S. Atomic Energy Commission.
[1] F. Boehm and A. H. Wapstra, Phys. Rev. 106, 1364 (1957).

F4. Energy Levels of B^9.* BOGDAN POVH,† *California Institute of Technology* (introduced by W. A. Fowler).—The energy levels of B^9 have been investigated by the $B^{10}(He^3,\alpha)B^9$ reaction.[1] At incident He^3 energies of 2, 2.5, and 3 Mev, alpha particles were analyzed by a magnetic spectrometer at an observation angle of 131° in the laboratory system. Alpha-particle groups leading to the ground, 2.33-Mev and 2.79-Mev states of B^9 have been observed. The widths of the 2.33-Mev and 2.79-Mev states were found to be about 80 kev and 300 kev, respectively. There is no evidence for a well-defined state corresponding to the suggested $1/2^+$, 1.75-Mev state in Be^9.[2] To investigate the region of B^9 between the excitation energies of 4 and 7 Mev, the alpha-particle spectrum was taken with the spectrometer at 90°. No well-defined level was observed in this region. The level structure is in agreement with similar unpublished work at the Rice Institute.[3]

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Assisted by a grant from the "J. Stefan" Institute, Ljubljana, Yugoslavia.
[1] Almquist, Allen, and Bigham, Phys. Rev. 99, 631(A) (1955).
[2] D. W. Miller, Phys. Rev. 109, 1669 (1958).
[3] D. Sweetman (private communication).

F5. Production of Terbium-149 from the Bombardment of Ta, Au, and Bi by High-Energy Protons. LESTER WINSBERG,* *University of California, Berkeley.*—The production of terbium-149 in Ta, Au, and Bi by protons with energies greater than 0.4 Bev was measured by direct counting of the alpha activity in the target foils and in adjacent aluminum foils. The latter were employed to catch any products that recoiled out of the target. Previously, the excitation functions of the alpha activity had been determined only to 3.0 Bev.[1] These were extended to 6.2 Bev. In order to determine the total cross section for the formation of terbium-149, the alpha-branching ratio was measured and found to be 0.10 ± 0.02. The fraction of terbium-149 recoiling out of the target both in the forward and backward directions was analyzed to provide further evidence as to the mechanism of the reaction.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Duffield, Friedlander, and Miller (unpublished).

F6. Gamma Rays from the 12.43-Mev Level in O^{16}.* D. F. HEBBARD, *California Institute of Technology* (introduced by W. A. Fowler).—Gamma rays from 12.43-Mev state of O^{16} to the ground state have been observed, using a 4×4 in. NaI crystal as detector in the reaction $N^{15}(p,\gamma)O^{16}$. This eliminates the spin and parity assignment 0^+ for the 12.43-Mev level. The only remaining possibility which is consistent with all other experimental evidence is the assignment 1^-.

Strong destructive interference is observed in the $N^{15}(p,\gamma)$ cross section in the energy region between the 1^- resonances at 12.43 and 13.09 Mev. For ground-state gamma radiation, the width of the 12.43-Mev level is 8 ev, and for the sum of all cascades through the 6 and 7-Mev levels, the width is 0.4 ev. In addition, there is a 35-ev width for decay by short range α-particle emission to the 4.43-Mev state of C^{12}.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

F7. Neutron Yields from Heavy-Ion Reactions. EDWARD L. HUBBARD, ROBERT M. MAIN,* AND ROBERT V. PYLE, *University of California, Berkeley.*†—A variety of metal targets have been bombarded by C^{12}, N^{14}, and Ne^{20} ions of various energies up to 124, 145, and 207 Mev, respectively. Neutrons produced in the targets were moderated and captured in a 3-ft cube of $MnSO_4$ solution and the resulting β activity from Mn^{56} was counted. Calibration of the $MnSO_4$ tank with a standard neutron source allows the determination of neutron yields from the Mn^{56} activity. For full-energy beam, neutron yields from thick targets vary from $(4.8\pm0.3)\times10^{-4}$ neutrons per incident ion for Ne ions on a carbon target to $(25.1\pm1.5)\times10^{-4}$ neutrons per incident ion for C ions on a uranium target. Yields are lower at reduced energies and go to zero at energies near the Coulomb barrier. Full-energy bombardments of thin targets give cross sections for producing one neutron that range from 1.1 ± 0.1 barns for C ions on beryllium to 20 ± 1 barns for Ne ions on lead. The data will be presented in more detail and compared with compound-nucleus and boil-off theories.

* Now at Tracerlab, Inc.
† This work was done under the auspices of the U. S. Atomic Energy Commission.

F8. Neutron Capture Chains in Heavy-Element Synthesis in Giant Stars.* D. D. CLAYTON AND W. A. FOWLER, *California Institute of Technology.*—If neutron captures in heavy-element synthesis in giant stars occur slowly enough to permit beta decay to the stable isobar before subsequent capture, the abundances in the resulting capture chain are given by $dN_A/d\tau=\sigma_A N_A+\sigma_{A-1}N_{A-1}$ for all atomic weights A.[1] The product of neutron flux and time is designated by τ. Approximate solutions to this set of equations have been obtained by solving the partial differential equation $(\partial/\partial\tau+\partial/\partial a)\sigma N=0$ where $\partial a=(1/\sigma)\partial A$. Observational data on the product σN indicate that seed nuclei, such as Fe^{56}, have been exposed to varying flux-time products or to varying numbers of neutrons in order to produce solar system abundances. The vast majority of the seed nuclei have been exposed only for small flux times resulting in one capture per nucleus on the average. Recent evidence for very small σN values for $A>200$ will be discussed as an indication of the maximum number of neutrons available per nucleus in stellar synthesis.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Burbidge, Burbidge, Fowler, and Hoyle, Revs. Modern Phys. **29**, 547 (1957).

F9. Abundances of Intermediate Mass Nuclei Produced by Rapid Neutron Capture in Supernovae.* R. A. BECKER† AND W. A. FOWLER, *California Institute of Technology.*—Following the method of Burbidge *et al.*,[1] calculations have been carried out for the abundances of nuclei in the region of mass numbers 145 to 185 produced by the rapid neutron-capture process thought to occur in supernovae. The mass differences of Johnson *et al.*[2] were used. The region is midway between the closed shells at 82 and 126 neutrons. The over-all results obtained are consistent with expected additional stability of nuclei in this region due to spheroidal deformation. The calculated abundances in this region agree, in general, with those listed by Suess and Urey,[3] with the exception of the rare earths in the range $A=170$ to 177. Our results favor an increase of relative abundances of these nuclei by a factor of about 5 and would more nearly be in accord with the relative abundances estimated by Noddack[3] for the heavier rare earths. The results support the calculations[1] which showed the effect of spheroidal deformation above the closed shell at $N=126$ in enhancing the production of Th^{232}, U^{235}, U^{238}, Cf^{254}, etc., in supernovae.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† On sabbatical leave from the University of Illinois. Partially supported by a grant from the Guggenheim Foundation.
[1] Burbidge, Burbidge, Fowler, and Hoyle, Revs. Modern Phys. **29**, 547 (1957).
[2] W. H. Johnson, Jr., and A. O. Nier, Phys. Rev. **105**, 1014 (1957); W. H. Johnson, Jr., and V. B. Bhanot, Phys. Rev. **107**, 1669 (1957).
[3] H. E. Suess and H. C. Urey, Revs. Modern Phys. **28**, 53 (1956).

F10. (Abstract withdrawn.)

F11. Study of Photoneutron Thresholds.* WILLIAM S. RAWLS,† *Iowa State College.*—Photoneutron thresholds of deuterium, lithium, manganese, copper, phosphorus, aluminum, vanadium, yttrium, lanthanum, praseodymium, and bismuth were studied using the Iowa State College synchrotron. Synchrotron bremsstrahlung was produced by deflecting the electrons onto the synchrotron target with a 360-degree knockout coil. Neutrons were detected by boron trifluoride proportional counters in conjunction with a delayed electronic gate. The synchrotron beam intensity was monitored by a transmission ionization chamber. The thresholds of some of the elements were remeasured using an energy and scaler switching circuit. In this method the photoneutron yield at some selected energy above threshold served as the beam intensity monitor. The binding energy of the last neutron was calculated from precision mass data and measured beta-decay Q values for several of the above elements. Plotting these binding energies *versus* the synchrotron energy control device, or integrator, "dekapot" setting yielded an energy calibration curve for the integrator. For some of the nuclides, breaks near threshold in the photoneutron curves were identified as due to transitions to the low-lying excited levels of the product nuclides.

* This research was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.
† On leave from Arizona State College at Tempe.

F12. Photodisintegration of He^4 Nuclei. D. L. LIVESEY, *University of British Columbia,* AND I. G. MAIN, *Queen's College, Dundee, Scotland* (introduced by J. B. Warren).—Helium gas at 6-atmos total pressure was exposed to bremsstrahlung of maximum energy 70 Mev from the beta syn-

chrotron at Queen's University, Kingston, Ontario, and photographic plates were used to detect the charged particles emitted. The tracks of He^3 particles produced by the (γ,n) reaction were identified by comparison with alpha-particle tracks introduced into the emulsions from the opposite direction. The estimated cross section for this reaction varies smoothly between (0.63 ± 0.10) mb at 40 Mev and (0.25 ± 0.04) mb at 60 Mev, the integrated cross section being (7.5 ± 0.5) Mev mb between these limits. The results agree closely with figures for the competing (γ,p) reaction published by Gorbunov and Spiridonov,[1] who used a cloud-chamber method. The yield of protons with energies above 15 Mev in the plates examined also agrees with the yield of He^3 particles for photons above 40 Mev. This and other evidence indicates that in this region the three-body and four-body disintegrations are of small importance compared with the (γ,n) and (γ,p) reactions.

[1] Gorbunov and Spiridonov, J. Exptl. Theoret. Phys. (U.S.S.R.) **33**, 21 (1957).

F13. Pile Neutron Capture Cross Section of Cu^{66}. T. O. PASSELL, *Stanford Research Institute,* AND R. L. HEATH, *Phillips Petroleum Company.*—The amount of nuclide Cu^{67} has been measured in neutron-irradiated copper oxide enriched to 98.2% Cu^{66}. After a 188-hour irradiation in the vertical hydraulic facility VH-4 of the Materials Testing Reactor (thermal neutron flux 1.6×10^{14} n/cm-sec) the copper oxide was subjected to a chemical purification procedure. The purified sample consisting of 2.3 mg of cuprous thiocyanate was analyzed for Cu^{67} using a 1½-in. diameter by 1-in. thick crystal of NaI (Tl) and a multichannel pulse-height analyzer. From the best available data on the decay of Cu^{67}, a 184-Kev gamma occurs in 45% of its disintegrations, and its half-life is 59 hours. Assuming these values to be correct, the capture cross section of 5.1 minute Cu^{66} for pile neutrons is 130 ± 30 barns. It is also necessary to assume the correctness of the measured value (2.1 barns)[1] for the $Cu^{65}(n,\gamma)Cu^{66}$ reaction cross section, since Cu^{66} was not observed in this experiment.

[1] H. Pomerance, Phys. Rev. **88**, 412 (1952).

F14. Spark Counters as Neutron Image Intensifiers.* L. REIFFEL, *Armour Research Foundation.*—The highly localized development of spark discharge channels suggests that spark counters may be useful as image intensification devices with very high gain. A novel neutron sensitive spark counter with an image resolution of the order of 8 lines/in. has been successfully applied to the problem of recording neutron Laue patterns. Using the Armour Research Reactor to provide a thermal neutron beam, Laue patterns have been recorded in less than 60 minutes at a thermal power level of 10 kw using a natural Boron converter plate to actuate the spark counter. Using enriched B^{10} converters implies exposure times of the order of 10 minutes at 10 kw. Certain neutron diffraction studies thus become practical at reactor powers below one kilowatt. Conversely, exposure times for reactor flux levels commonly employed in such work become quite short. The counter employed in most of the work uses 80 anode wires and 81 cathode wires covering a sensitive area of 18.5 cm×20 cm. Its possible application to other problems involving either slow or fast neutrons will also be discussed.

* Supported in part by the Armour Research Reactor Participator Program.

F15. Decay of Bound Muons in Fe and Cu.* F. E. HOLMSTROM AND J. W. KEUFFEL, *University of Utah.*—The spontaneous decay rate $\lambda_d(Z)$ is being measured for muons stopping in heavy elements using an improved cosmic ray apparatus with large scintillators (2 ft×2 ft) and a large acceptance angle. The composite time distribution of decay electrons from cosmic-ray muons is measured in aluminum and in heavy elements. The aluminum is used to eliminate the need to determine absolute efficiencies assuming $\lambda_d(13)=\lambda_0$=rate for free muon decay. We find $\lambda_d(26)/\lambda_0=1.19\pm0.10$, confirming the anomaly at $Z=26$.[1] Measurements for other elements including copper are in progress. Since existing measured disappearance rates $\lambda(Z)$ for Cu disagree with each other and theory, we have measured the decay curve of capture radiation for this element. The mean life is 163 ± 6 mμsec based on runs totaling 201 hr. A similar measurement gave 201 ± 12 mμsec for Fe. If we combine our best mean lives with the electron counting results of Lederman and Weinrich[2] we get $\lambda_d(26)/\lambda_0=1.15\pm0.06$ and $\lambda_d(29)/\lambda_0=0.90\pm0.08$.

* Assisted by the National Science Foundation.
[1] Lundy, Sens, Swanson, Telegdi, and Yovanovitch, Phys. Rev. Letters **1**, 102 (1958).
[2] L. Lederman and M. Weinrich, Proc. CERN Symposium **2**, 247 (1956).

TUESDAY MORNING AT 9:30

Chemistry 2250

(H. TICHO presiding)

Symposium on High-Energy Physics I

G1. π-e Decay Observations at Cern. ALVIN V. TOLLESTRUP, *California Institute of Technology.* (20 min.)

G2. π-e Decay. JACK STEINBERGER, *Columbia University.* (10 min.)

G3. π-e Decay Observations at University of California Radiation Laboratory. KENNETH M. CROWE, *University of California, Berkeley.* (20 min.)

G4. Comparison of the Beta Spectra of B^{12} and N^{12}. HENRY HILTON, *California Institute of Technology.* (20 min.)

G5. Status of the Theory of Weak Interactions. MURRAY GELL-MANN, *California Institute of Technology.* (40 min.)

G6. Asymmetries in Hyperon Decay. RODNEY L. COOL, *University of California, Berkeley.* (20 min.)

TUESDAY MORNING AT 9:30

Franz Hall 104

(R. A. SATTEN presiding)

Solid State Physics II

Invited Paper

H1. Mechanism of Donor Formation in Heat-Treated Silicon. W. KAISER, *Bell Telephone Laboratories.* (30 min.)

Contributed Papers

H2. Infrared Absorption Spectrum of Lithium Hydroxide. KENNETH A. WICKERSHEIM, *University of California, Los Angeles.*—Techniques have been developed for the production of single-crystal samples of lithium hydroxide. Complex polarized absorption spectra, resembling those of magnesium hydroxide[1] and calcium hydroxide[2] in the 2.7-micron region, have been obtained. The hydrogen positions in lithium hydroxide have been deduced. The normal modes of the crystal symmetric under lattice translations have been constructed approximately. Factor group selection rules have been deduced for the fundamentals and binary combinations arising from those modes. On the basis of this analysis it has been possible to explain the near infrared spectrum of LiOH. The bands in the 2.7-micron region have been assigned to the antisymmetric OH stretching fundamental and to binary combinations of lattice modes with both the symmetric and the antisymmetric OH stretching fundamentals. Reasonable assignments of the deduced lattice frequencies to specific lattice modes have been made. All lattice frequencies deduced lie below 700 cm^{-1} and have yet to be observed directly in either the infrared or Raman spectrum.

[1] R. T. Mara and G. B. B. M. Sutherland, J. Opt. Soc. Am. **43**, 1100 (1953).
[2] W. R. Busing and H. W. Morgan, J. Chem. Phys. **28**, 998 (1958).

H3. Near-Infrared Absorption Spectrum of Beryl. ROBERT A. BUCHANAN AND KENNETH A. WICKERSHEIM, *University of California, Los Angeles.*—The high-dispersion polarized spectra from one to three microns of several samples of beryl collected from widely scattered locations are presented. Each spectrum is different. The spectra show many sharp lines, the positions of which suggest strongly that different forms of hydroxide impurities are present in all the samples studied. The three possibilities considered for the origin of these bands are: (1) water molecules trapped in the channels formed by the crystal lattice, (2) other hydroxide impurities trapped in the channels, and (3) hydroxide ions substituted for ions of the beryl crystal. An analysis of the spectra shows that in some crystals water molecules are present oriented with their H−H line along the channels, but that at least one other hydroxide impurity is present in varying amounts with its changing dipole moment oriented along the channels. The observed dichroism suggests that random substitution of hydroxide ions in the crystal lattice is not present in some crystals but possible in others.

H4. Vibration Spectra and Specific Heats of Diamond-Type Lattices. JAMES C. PHILLIPS, *University of California, Berkeley.*—A method is presented for calculating the frequency distribution of a crystal from measured dispersion curves without constructing a force constant model. The method is then used to compute a vibration spectrum for Ge based on the dispersion curves measured by slow neutron scattering. The vibration spectrum is used to calculate the lattice specific heat, the results agreeing with experiment to within a few percent. A slightly modified distribution yields results agreeing to within one percent. The results are sufficiently detailed to show the necessity for including corrections due to anharmonicity even at $T \sim \theta/2$. By analogy with the results for Ge vibration spectra are constructed for silicon and grey tin that also give good agreement with the specific heat measurements; from the spectra and also by analogy with Ge the dispersion curves for silicon and grey tin can be sketched. A similar discussion is also given for InSb and diamond.

H5. Electron Mobility Along Charged Dislocations.* F. M. WANLASS AND P. GIBBS, *University of Utah.*—Authors[1] found 0.3 v activation energy for electronic dielectric loss evidently associated with impurity along dislocation[2] in α-Al_2O_3 (band gap >5 v), suggesting that energy bands are strongly warped locally (~2 v change). The mobility of electrons subjected to a simple cylindrical electrostatic potential $\psi_r = -e(1-r/a)$ has been calculated by a modification of Schrieffer's[3] method. Diffuse scattering was assumed near the dislocation line, so that $f_1 = 0$ at $r \leq a$. With simplification, this gives $\mu_{eff} = \mu_{bulk}(2\alpha/\pi^{\frac{1}{2}})[1-[2\beta/3(1+\beta)]]$ for $\alpha \to 0$ and $\mu_{eff} = \mu_{bulk}$ for $\alpha \to \infty$, where $\alpha = a(2kTm)^{\frac{1}{2}}/\tau l$, $\beta = kT/l$. If the carrier density derives entirely from ionization at the dislocation core, $\mu_{eff} = (4aR/q)(2\pi kT/m)1/N$ for small α and small β, and the conductivity varies with $T^{\frac{1}{2}}$. For reasonable values of parameters μ_{eff} can be two orders of magnitude less than μ_{bulk}.

* Supported by the Office of Naval Research.
[1] F. M. Wanlass and P. Gibbs (to be published). See P. Gibbs, *Edicott House Convention* (John Wiley and Sons, Inc., New York, 1958).
[2] R. N. Tucker and P. Gibbs, J. Appl. Phys. **29**, 1375 (1958).
[3] J. R. Schrieffer, Phys. Rev. **97**, 641 (1955).

H6. Theory of Edge Emission Phenomena in ZnO and CdS. J. J. HOPFIELD, *Bell Telephone Laboratories.*—Tentative symmetry assignments of *P*-valence bands and *S*-conduction bands can be made for ZnO and CdS on the basis of a tight-binding model. The sixfold degenerate *P*-bands are split in hexagonal crystals by the crystal field and spin-orbit coupling. The polarization of recombination radiation depends upon which band the hole belongs to, and is almost independent of the recombination mechanism. The polarization of the edge emission (the series of equally spaced emission lines) should therefore be strongly temperature dependent. Quantitative agreement is obtained between the predictions of this band model for CdS and the edge emission polarization experiments of Dutton.[1] It is shown that the intensity distribution of edge emission cannot be reasonably explained without the introduction of impurities or surfaces to absorb crystal momentum. In CdS, recombination from a shallow trap seems necessary to explain the large coupling to the lattice apparent in the observed emission spectrum. The edge emission spectrum should approximate a Poisson distribution for recombination from a trap. The mean number of emitted phonons is a measure of the radius of the trapped carrier wave function.

[1] D. Dutton, J. Phys. Chem. Solids **6**, 101 (1958).

H7. Electrocaloric Effects at the Paraelectric to Ferroelectric Transition in Colemanite. H. H. WIEDER, *U.S. Naval Ordnance Laboratory.*—The ferroelectric transition temperature T° of

colemanite, $CaB_3O_4(OH)_3 \cdot H_2O$ depends upon an externally applied electric field E_z, as well as upon the internal electric E_i generated by its own space charge. T_c increases as $(E_z+E_i)^{\frac{1}{2}}$ in agreement with thermodynamic considerations for a second-order transition and in contrast to a first-order transition where T_c is linearly dependent upon E. Experimental results showing the dependence of the Curie constant upon the clamping of the polarization by the electric field, the temperature dependence of the spontaneous polarization, and the induced paraelectric polarization[1] are in agreement with the phenomenological theory of Devonshire.[2]

[1] A. F. Devonshire, Brit. Elect. and Allied Ind. Research Associates, Technical Report L/T 185, (1948).
[2] A. F. Devonshire, Advances in Phys. 3, 85 (1954).

H8. Conductivity in PbS Films from dc to 10 kMc/sec.* D. P. Snowden and A. M. Portis, *University of California, Berkeley,* and R. F. Brebrick, *U.S. Naval Ordnance Laboratory.*—Measurements of conductivity and photoconductivity as a function of frequency from dc to 10 kMc/sec have been made on chemically deposited lead sulfide films. In addition, the mobility of dark and photocarriers has been determined at dc by measurement of the Hall effect and at 10 kMc/sec by microwave Faraday rotation.[1] The electrode design used for the rf measurements avoids the apparent increase in conductivity which has been analyzed by Lax and Sachs[2] as a self-capacitance effect. The increase in conductivity observed in the present experiments is believed to be characteristic of the electrical structure of the sample. All samples exhibit a conductivity which is relatively insensitive to frequency up to about 100 Mc/sec. Within a decade of this frequency the conductivity increases by nearly an order of magnitude and then remains constant again into microwave region. The photoconductivity on the other hand is essentially constant over the entire frequency range with a broad hump in the 100-Mc/sec range. These results lend support to a model for PbS films consisting of alternate *n*-type and *p*-type regions,[3] provided that the contribution of minority as well as majority carriers in both regions is considered.

* Supported in part by the Office of Naval Research, the Signal Corps, the National Security Agency, and the Air Force Office of Scientific Research.
[1] A. M. Portis, "Conference Proceedings, 1958 International Conference on Semiconductors," J. Chem. Phys. Solids (to be published).
[2] M. Lax and R. Sachs, Phys. Rev. 107, 650 (1957).
[3] J. C. Slater, Phys. Rev. 103, 1631 (1956).

H9. Noise and Signal Response in PbS Photoconductive Films.* H. E. Spencer, *Eastman Kodak Company.*—Experimental noise and signal response data of two PbS photoconductive films have been obtained as a function of frequency and wavelength at temperatures ranging from about 25°C to −173°C. Good agreement between experiment and a theory proposed by Petritz is found. The theory is used in such a way that correlations between noise and response may be made independent of the temperature. The measured time constants enter into the correlations only indirectly; they are necessary only to extrapolate data measured at a given frequency to some lower frequency. Generation-recombination (G-R) noise predominates at all temperatures. Time constants measured by noise and by response agree. The role of absorbed ambient photons is described. These photons are important at the lower temperatures. The concentrations of the majority carriers (holes) and their mobility as derived from signal data are listed.

* Work supported by a contract with the Navy Bureau of Ordnance.

H10. Colloidal Metal in Alkali Halide Crystals.* Paul H. Shlichta, *California Institute of Technology.*—Crystals of NaCl and KCl, containing Cu^+, were grown from melt and treated with sodium vapor at elevated temperatures. A red coloration resulted which was attributed, by absorption spectra analysis, to colloidal particles of copper metal. Similar results were observed in crystals containing Cr, Mn, Ni, Ag, and Cd. A comparison will be made between these colloidal dispersions and pure, additively colored crystals, the "colloidal" band of whose absorption spectra is generally attributed to particles of alkali metal. Scott[1] has shown that this coloration is due to aggregates of at least 10 alkali atoms or their equivalent, and various calculations,[2] based on the Mie scattering theory, have given qualitative agreement with observed absorption spectra. It is proposed, however, that the "colloidal" band can be accounted for, qualitatively, merely in terms of aggregates of *F* centers. The two models are related in that the extreme case of *F*-center aggregation is equivalent to particles of face-centered-cubic alkali metal. Arguments for both models will be discussed and it will be shown that temperature dependence of magnetic susceptibility distinguishes between them.

* Portion of doctoral thesis, Division of Chemistry and Chemical Engineering, California Institute of Technology. Author now at Jet Propulsion Laboratory, California Institute of Technology.
[1] Scott, Smith, and Thompson, J. Phys. Chem. 57, 757 (1953).
[2] M. Savostianova, Z. Physik 64, 262 (1930); D. R. Westervelt, North American Aviation Corporation private report, 1954; W. T. Doyle, Phys. Rev. 111, 1067 (1958).

H11. Some Properties of Green and Red-Green Luminescing CdS. Y. T. Sihvonen, D. R. Boyd, and C. D. Woelke, *General Motors Corporation.*—A series of electro-optical experiments at room temperature have been made with two types of high purity single crystals of CdS. Type A, believed to have near-perfect stoichiometry luminesces green (5145 A) under 3650 A ultraviolet radiation, has low dark conductivity (2.5×10^{-11} mho cm^{-1} at 300°K), exhibits no photopeak, and has a relatively short carrier lifetime (less than 4 μsec). Type B, believed to have a sulfur deficiency, luminesces first strongly red (≅7200 A), then strongly green (>5145 A) as the exciting radiation is increased in intensity. Simultaneously both emissions shift toward longer wavelengths. Also, as the red emission intensity begins to saturate, the intensity-rate change of conductivity abruptly changes. It is suggested that red luminescence is the result of a free hole capture by one of the electrons residing in a sulfur vacancy. This trapping sensitizes the crystal but at the expense of increasing carrier lifetime to millisecond magnitudes. Furthermore, some of these vacancies (~0.4 ev below the conduction band) act as donors to increase dark conductivity (about 10^{-9} mho cm^{-1} at 300°K).

Tuesday Morning at 10:00

Chemistry 2276

(A. Baños presiding)

Plasma Physics and Other Topics

I1. Electrodynamic Containment of a Charged Particle by Three-Phase Voltages. R. V. Langmuir, H. M. Goldenberg, and R. F. Wuerker, *The Ramo-Wooldridge Corporation.*—The containment of charged micron size dust particles by static and electric fields has been reported.[1] As a variation on this theme we have contained these particles by three-phase

alternating electric fields along with superimposed dc electric fields. The particles were injected into the interior of a cube formed by insulated planar metallic conductions. Opposite sides of this box are electrically connected together externally, and the three resulting leads are attached to a "Y"-connected three phase source. A dc voltage could be connected into one or two legs of this supply. The motion of a particle in these fields consists of a large-amplitude oscillation upon which is superimposed a rapid jiggle motion at the driving frequency. The former or "resultant frequency" has been measured experimentally as a function of the amplitude of the ac voltage (at both 60 and 400 cycles) by observing visually the particle resonance to an ac signal applied between opposing electrodes. By varying both the amplitudes of the ac and dc suspension voltages, the stability boundaries have been determined experimentally.

[1] Shelton, Wuerker, and Langmuir, Bull. Am. Phys. Soc. Ser. II, 2, 375 (1957).

I2. Electrodynamic Containment of Many Charged Particles by Three-Phase Voltages. R. F. WUERKER, H. M. GOLDENBERG, AND R. V. LANGMUIR, *The Ramo-Wooldridge Corporation.*—The three-phase electrodynamic suspension system described in the previous abstract is also capable of containing many charged particles in dynamic equilibrium against gravitational and interparticle forces. It has been found experimentally that when the initial kinetic energy of the particles is damped, they will form a stable "crystalline" array characteristic of the symmetry properties of the externally applied static and alternating fields. Because of the three-phase characteristic of these fields, the individual particles execute elliptical trajectories about their equilibrium sites. On increasing the effective binding (by either increasing the applied voltage or decreasing the frequency) the "space crystal" can be compressed until the dynamic interaction of the particles causes the array to "melt." By again decreasing the external effective electrical binding and damping the motion, the space crystal again can be reformed. These features will be demonstrated by showing motion pictures of the containment of charged aluminum particles several microns in diameter by 60- and 400-cycle driving signals.

I3. Viscosity of Dusty Gases. W. T. SPROULL, *Western Precipitation Corporation.*—Experiments show that the viscosity of a gas, such as air at ordinary room temperature and pressure, decreases about 40% from its usual value (around 180 micropoises for air, to a value around 110 micropoises) when a dust (such as rock dust) is suspended in it at a concentration of the order of 100 grains per cubic foot (roughly 250 grams per cubic meter). The effect may be explained partly by regarding the dust cloud as a very low viscosity "gas" mixed with the true gas and partly by the reduction of the molecular "persistence of velocity" by the dust particles. This effect is significant in rating the gas flow capacity of cyclonic dust collecting equipment and also may be significant in other areas of physics, such as meteorology, cosmology, etc. For a given pressure gradient, the rate at which a dusty gas flows turbulently through a pipe or orifice increases above the clean gas flow rate by an amount proportional to the square root of the dust concentration, and according to L. W. Briggs the increase amounts to about 6½% when the concentration is 100 grains per cubic foot. This empirical relation may not hold above 200 grains per cubic foot.

I4. On the Origin of Cosmic Rays during the Early Part of the Evolution of Our Galaxy. L. BIERMANN AND LEVERETT DAVIS, JR.,* *Max-Planck-Institut für Physik, Göttingen.*—The hypothesis is considered that the volume in which the cosmic rays are stored is comparable to that of the halo of our system, and hence (if the total amount of gas in the halo is at most comparable with that in the disk) the average cosmic-ray lifetime is comparable with the age of the galaxy. Reasons are given which indicate that the amount of interstellar gas, the number of early type stars, and the rate of production of cosmic rays were much greater in the early part of the evolution of our galaxy than they are now. It is shown that under these conditions the observed data on the cosmic-ray isotropy, including that of the very high-energy component, and the data on the abundances of the Li, Be, B nuclei may be understood, and that in addition the conditions for the statistical (Fermi type) mechanisms of acceleration to be operative were much more favorable in the early stages than they are now.

* National Science Foundation Fellow; permanent address: California Institute of Technology.

I5. Reflectivity of a Meteor Trial in a Magnetic Field. IRA L. KARP, *Boeing Airplane Company.*—Previous analyses by Herlofson[1] and Lovell and Clegg[2] of radio reflections from meteor trails have been based on the assumption that the electrons in the trail are not moving and are not in a magnetic field. In this analysis the reflectivity of the trail for electromagnetic waves of wavelength comparable to the trail diameter is presented as a function of the parameters of the incident wave, as well as those of two new variables: (a) a finite electron temperature, and (b) a magnetic field at an angle to the trail. The analysis is based on the Born approximation, and correction terms for higher density trails or large-diameter trails are estimated. Suggested measurements of the local magnetic field inside the trail based on differences of scattering cross section between right and left circularly polarized waves are presented along with possible physical sources of large local magnetic fields and implications for observed anomalous stability of trails.[3]

[1] N. Herlofson, Arkiv Fysik, 3 (1951).
[2] Lovell and Clegg, Proc. Phys. Soc. (London) 60, 491 (1948).
[3] Ratcliffe, Nature 162, 9 (1948).

I6. Unexcited Plasma. JAMES E. DRUMMOND, *Boeing Scientific Research Laboratories,* AND DAVID B. CHANG, *California Institute of Technology.*—An analysis of growing waves and instability due to P. A. Sturrock[1] is applied to a portion of the Bohm and Gross[2] theory of plasma oscillations to explain the negative results of the experimental attempts of Looney and Brown[3] to excite oscillations by the sheathless injection of an electron beam into a homogeneous plasma. It is shown how the analysis enables one to distinguish between evanescent and amplifying waves and between convective and nonconvective instability by inspection of the associated dispersion laws. Application to the dispersion law for a monoenergetic electron beam in a homogeneous zero-temperature plasma shows that the only instability present is convective. This suggests that the oscillation prediction of Bohm and Gross should be replaced here by a prediction of amplification: no oscillations should be excited, but rather fluctuations in the beam should be amplified in traversing the plasma.

[1] P. A. Sturrock, "The kinematics of growing waves," Internal memorandum M. L. No. 492, Microwave Laboratory, W. W. Hansen Laboratories of Physics, Stanford University (1958).
[2] D. Bohm and E. P. Gross, Phys. Rev. 75, 1851 and 1864 (1949); Phys. Rev. 79, 992 (1950).
[3] D. H. Looney and S. C. Brown, Phys. Rev. 93, 965 (1954).

I7. Hydromagnetic Flow in a Circular Pipe. K. P. CHOPRA, *University of Southern California* (introduced by H. T. Yang).—This paper describes the flow of an electrically conducting liquid in a circular pipe when a uniform magnetic field is applied transverse to the flow direction. It is found that the velocity profile of the liquid transforms itself from a parabola into a plateau as a magnetic field of greater strength is applied. This suggests that the induction drag is important in the central layers while the ordinary viscosity is dominant near the channel walls. These findings support the earlier experimental results of Hartmann and Lazarus. It is also shown that the treatment, though elementary in nature, is

quite rigorous and does not need correction for the e.m. shielding.

I8. Containment Time of One-Half-Mev Positrons in a Magnetic Mirror Machine.* GORDON GIBSON† AND EUGENE LAUER, *University of California, Livermore.*—A dc magnetic mirror machine has been constructed to study nonadiabatic effects on the single-particle containment time. The Livermore 90-in. cyclotron is used to produce Ne^{19}, (β^+ 2.3 Mev end-point energy, 18-sec half-life) which is originally stored in an auxiliary tank and then allowed suddenly to fill the containment region by opening a 20-in.-diameter gate valve (opening time $\cong$0.04 sec). The mean containment time is obtained by observing the transient buildup of counting rate of the positrons escaping from one end of the machine. With a 900-gauss central field, a mirror-to-mirror distance of 64 in., a mirror ratio of 1.8, a 1.5-in.-diameter counter located on axis and set for $\frac{1}{2}$ Mev $\pm$27%, 12% of the isotropically emitted positrons are observed to be initially trapped and to have a mean containment time of about 0.7 sec. This is consistent with the time for small-angle multiple scattering to cumulate to 1 radian in the 2.1- $\times 10^{-6}$-mm Hg of stable neon which was added.

* Work done under the auspices of the U. S. Atomic Energy Commission.
† Visiting from Westinghouse, Atomic Power Department.

I9. Energetic Plasma Source.* F. H. COENSGEN, W. F. CUMMINS, AND A. E. SHERMAN, *University of California, Livermore.*—A plasma source similar to that used previously in an ion source[1] has been constructed of deuterated titanium washers interleaved with ceramic spacers to form a cylinder with an internal diameter of 0.5 in. An ARC of several thousand amperes with a half-period of 5 μsec is initiated within the washer stack. The energy distribution of the ions in the plasma which is discharged from the open end has been studied by means of a magnetic momentum analyzer followed by an electrostatic energy analyzer. Time-of-flight measurements are made concurrently and show that the ions leave the source with the measured energy rather than gain it from spurious space-charge effects, such as a sheath at the analyzer slit. The highest ion energies are obtained with a positive voltage applied to the open end of the source and for a minimum impedence in the arc current supply. For typical conditions the measured mean energy of the D^+ ions is a few hundred ev.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] Ehlers, Gow, Ruby, and Wilcox, Rev. Sci. Instr. 29, 614 (1958).

I10. Elementary Theory of the Fast, Nonadiabatic, Transverse Pinch. BURTON D. FRIED, *Space Technology Laboratories.*—The characteristics and elementary (collisionless) dynamics of the fast, nonadiabatic transverse pinch (I_θ, B_z) are analyzed, using Rosenbluth's self-consistent theory of the pinch interface as a basis. As with the longitudinal pinch (I_z, B_θ), to achieve pinch velocity v with gas density ρ requires condenser electric fields $E \gtrsim (v/c)^3(4\pi\rho c^2)^{\frac{1}{2}}$. This suggests the use of the same type of radial condenser currently being used here to study fast longitudinal pinches, the plates, however, being terminated at a coil around the pinch tube rather than at electrodes. (Operation of this condenser in a *TE* rather than *TEM* field mode, thereby avoiding the necessity for a coil, is attractive but it can be shown that only the *TEM* mode gives the required energy convergence.) Optimization of coil pitch and gas density leads to high-pitch angles (e.g., 80°) and to a higher gas density for given condenser voltage than with the longitudinal pinch. Absence of a singularity in B at zero radius makes the energy transfer less sensitive to the radius at which bouncing first occurs, and theoretical energy transfers of 50% with inputs of 10-kev per deuteron are predicted. Since the optimum coil inductance is much larger than the intrinsic condenser inductance, the current is much more sensitive to pinch radius, thus facilitating diagnostics. Theoretical curves of pinch radius, current, voltage, and particle energy will be shown.

TUESDAY AFTERNOON AT 1:30

Chemistry 2250

(G. CHEW presiding)

Symposium on High-Energy Physics II

J1. K^+ Scattering in Emulsion. DONALD H. STORK, *University of California, Los Angeles.* (15 min.)

J2. K^+ Charge Exchange. MARIAN M. WHITEHEAD, *University of California, Berkeley.* (15 min.)

J3. K^+ Scattering on Protons. LEROY T. KERTH, *University of California, Berkeley.* (15 min.)

J4. K and π Scattering on H and D (600 to 2500 Mev/c). R. A. SCHLUTER, *Massachusetts Institute of Technology.* (20 min.)

J5. K^- Capture on Deuterium. JOSEPH J. MURRAY, *University of California, Berkeley.* (20 min.)

J6. Interpretation of K^- Deuterium Captures. RICHARD H. DALITZ, *University of Chicago.* (40 min.)

J7. Photoproduction of Pions (500 to 1000 Mev). ROBERT L. WALKER, *California Institute of Technology.* (20 min.)

TUESDAY AFTERNOON AT 2:00

Franz Hall 104

(J. HOLMES presiding)

Solid-State Physics III

Invited Paper

K1. Characteristics of Magnetostatic Modes of Ferrimagnetic Spheres. ROBERT L. WHITE, *Hughes Aircraft Company.* (30 min.)

Contributed Papers

K2. X-Ray Dispersion in the 5 to 50 A Wavelength Region.* BURTON L. HENKE AND JACK C. MILLER, *Pomona College.*—The complex atomic scattering factors for the light elements C_6 to Ge_{32} and for the long wavelength x-ray region have been calculated from mass photoelectric absorption coefficients[1] using an integral relationship given by the quantum mechanical theory of dispersion.[2] The anomalous scattering due to electron "resonances" at the K and the L critical absorption edge wavelengths has been found to be more extensive than that predicted by the older dispersion theories. The reflection efficiency as a function of both angle of reflection and of wavelength has been calculated for a quartz and an aluminum mirror from the atomic scattering coefficients. The predicted reflection curves are found to be in good agreement with those obtained experimentally.† Ultrasoft x-ray interactions as absorption, diffraction, grazing incidence reflection, and transmission are being investigated as bases for the analysis of microscopic systems for structure, mass, and chemical information.

* Supported by the Air Force Office of Scientific Research.
[1] Henke, Lundberg, and White, J. Appl. Phys. **28**, 98–105 (1957).
[2] R. W. James, *Optical Principles of the Diffraction of X-Rays* (G. Bell and Sons, London, 1954).
† Compiled for us by Mr. George Johnson, Stanford University.

K3. Calculation of Ultrasoft X-Ray Dispersion Coefficients.* JACK C. MILLER AND BURTON L. HENKE, *Pomona College.*—The semiempirical method described in the previous paper[1] for the calculation of atomic form factors in ultrasoft x-ray dispersion theory leads to the extensive application of numerical techniques, particularly in integrations involving singularities within the range of integration. In this case we have resorted to the usual Cauchy's principal value definition, and have employed a modified form of Simpson's rule applicable to a rational function for the integrand. A further difficulty is encountered in attempting to perform the integration under limiting conditions on certain parameters of the integrand. In these calculations we were assisted by the personnel and facilities of the Western Data Processing Center of UCLA. A program for the calculation of transmission efficiencies of ultrasoft x-rays at grazing incidence through thin films forms an additional part of the present study. This work uses the standard two surface optics as given, for example, by Wolter.[2] The latter calculation was performed on the computing facilities of the Millikan Laboratory, Pomona College, Claremont.

* Supported by the U. S. Air Force Office of Scientific Research.
[1] B. L. Henke and J. C. Miller, Bull. Am. Phys. Soc. II, 3, 413 (1958), preceding abstract.
[2] H. Wolter, "Optik dünner Schichten" (Table I), *Handbuch der Physik* (Springer-Verlag, Berlin), Vol. 24.

K4. Mass Analysis of Photoionization Products in Nitrogen and Nitrous Oxide.* J. A. R. SAMSON AND G. R. COOK, *University of Southern California* (introduced by G. L. Weissler).—Identification of ionized fragments produced by irradiating N_2 and N_2O with monochromatic radiation between 460 A and 1000 A has been made possible by combining a vacuum ultraviolet monochromator with a mass spectrometer. Ionization limits and dissociative ionization energies are estimated from graphs in which ions per unit photon flux *versus* wavelength are plotted. The ionization limits are compared with previously reported spectroscopic results, while the dissociative ionization energies are compared with calculated and electron impact data. The results agree well with literature data, and further, favor dissociation energies of 9.76 ev and 6.49 ev for N_2 and NO, respectively.

* The support of this work by ONR and by the Cambridge Air Force Research Center is gratefully acknowledged.

K5. Photoionization Induced Ion-Molecule Reactions in a Mass Spectrometer.* G. R. COOK AND J. A. R. SAMSON, *University of Southern California, Los Angeles* (introduced by G. L. Weissler).—H_3^+ and N_2H^+ ions have been observed in the ionization chamber of a Nier type mass spectrometer when H_2 and a mixture of H_2 and N_2, respectively, were photoionized by radiation from a Seya type vacuum ultraviolet monochromator. The appearance of H_3^+ was found to begin at the ionization potential of H_2, 15.3±0.5 ev, and curves of the ratio of ions per photons *versus* wavelength were obtained for both the H_3^+ product ion and the H_2^+ reactant ion. At 765 A the pressure dependence of the ion intensities were determined over the range 0.3×10^{-4} to 30×10^{-4} mm Hg. Since the monochromator light source was pulsed, delay times between the formation of H_2^+ ions and their arrival at the collector could be measured with an oscilloscope. Thus, the time spent by the H_2^+ in the ionization chamber could be calculated and was of the order of 10^{-6} sec. The rate of the reactions $H_2^+ + H_2 \rightarrow H_3^+ + H$ was determined from a plot of the intensity ratio of $H_3^+/(H_3^+ + H_2^+)$ *versus* the H_2 concentration and was found to be of the order of 10^{-9} cm³/molecule sec, in agreement with electron impact experiments.[1] Results of a similar nature have also been obtained for the formation of N_2H^+.

* The support of this work by the Office of Naval Research and by the Cambridge Air Force Research Center is gratefully acknowledged.
[1] D. B. Stevenson and D. O. Schissler, J. Chem. Phys. **23**, 1353 (1955); *ibid.* **29**, 282 (1958).

K6. Coherent Phase Large Area Magnetron Anode.* C. W. HARTMAN AND D. H. SLOAN, *University of California, Berkeley.*—A cavity resonator has its cylindrical outer surface cut into many parallel strips or bars. These are coupled to the interior by loops connected between adjacent bars. Neighboring loops are joined into a continuous hoop extending around the cavity. Several hoops and the attached bars form the cylindrical outer wall of the cavity which is the anode of a magnetron, surrounded by a cathode. The low impedance hoops and bars prevent buildup of voltage between bars to interact with encircling electron beam, except across the coupling loops where both *TM* mode of cavity and resonant frequency of loops have sufficient impedance. The latter is much higher frequency and not excited by electron beam synchronized to pass bars at cavity frequency. Intense electric field along cavity axis can be reversed at intervals of $\lambda/2$ for linear accelerator. Magnetic instead of electric coupling through loading discs gives this mode the lowest frequency, chosen by magnetron. Zero group velocity is avoided by pre-excitation propagated in cathode space. Anode and cathode area may be hundreds of times greater than usual.

* The research reported herein has been made possible through the support extended by the Electronic Components Laboratory of the Wright Air Development Center under Contract No. AF 33(616)-3278.

K7. Glow Magnetron.* S. L. MERCER, C. W. HARTMAN, AND D. H. SLOAN, *University of California, Berkeley.*—High voltage cycloidal glow in crossed fields does not arc where thousand gauss magnetic field is parallel to the concentric cylindrical electrode surfaces. Gradually curved fringing field prevents extension of glow to regions lacking crossed field arc protection. Air, between 10^{-3}- and 10^{-5}-mm Hg pressure, allowed 30-kv 600-amp millisec pulses. Cycloidal glow exceeding one amp initiated plasma oscillations which backbombarded the aluminum cold cathode, and provided secondary emission which grew as in magnetrons. Gas increased perveance tenfold. Aluminum oxide sputtered away is largely ionized and returned. 10^{-6} mm oxygen maintained sensitive cathode surface in presence of hydrogen glow. Ordinary magnetron, inside out, was 50% efficient at 100-kw input. For higher power a large anode area will be tightly coupled to the high Q (10 000) cavity interior of anode to avoid parasitic oscillation modes. This single tuned circuit resonance

transformer puts a few thousandths of the cavity voltage between adjacent anode bars, interacting with circumferential electron beam. Interior *TM* modes are correct for linear accelerators. *TE* modes could heat plasma near resonator axis. Load receives rf without circuits or insulators.

* The research reported herein has been made possible through the support extended by the Electronic Components Laboratory of the Wright Air Development Center under Contract No. AF 33(616)-3278 and the Air Force Cambridge Research Center under Contract No. AF (19(604)-2270.

K8. On the Radial Eigenfunctions and Asymptotic Phase Shifts of Electrons Scattered by Hartree Potentials. W. J. BYATT AND F. O. LANE, JR., *Sandia Corporation.*—Radial eigenfunctions and asymptotic phase shifts for electrons elastically scattered by the Hartree potentials of He, N, O, A, Kr have been found. An analogue computer, with the Hartree potential inserted by a function generator of accuracy of the order of better than 2% was used in the work. The potential function generator can be blanked out so that a free particle solution (spherical Bessel function) can be directly compared with the eigenfunction resulting from the inclusion of the potential. This has the advantage that the phase shift can be read directly from the plots. The body of this report will consist of presentation of results of the calculations and, where possible, a comparison with previous published results will be made; the over-all accuracy will also be discussed. The energy domain considered is nonrelativistic.

K9. Kinetics of Electrical Conduction along Dislocation in Al_2O_3.* H. B. VANFLEET, G. S. BAKER, AND P. GIBBS, *University of Utah.*—Experiments[1] have shown that metallic backing may be drawn through Al_2O_3 crystals by a charged probe. On contact of a negative probe (−300 v) at 530°C, the current increased exponentially, with a time constant of about 0.5 millisec. With positive potential, the current rose to the maximum negative probe value, then dropped off more than tenfold to a steady-state value. When the positive probe touched virgin surface, the current rose from zero directly to this same steady state value. $i_0 \exp(-H/RT)$ represented asymptotic current for both positive and negative probes, where H was 21 and 34 kcal/mole for platinum and silver backing, respectively. For negative probes, at temperatures above that at which material was observed to be drawn from the crystal, an abrupt tenfold increase in current, and an increase in H to 26 and 51 kcal/mole was observed for platinum and silver backing, respectively. This current jump may result from the sudden appearance of metallic film on the upper surface, interconnecting dislocations and changing the slow process.

* Supported by the Office of Naval Research.
[1] Vanfleet, Baker, and Gibbs, Bull. Am. Phys. Soc. Ser. II, 3, 359 (1958), and letter submitted to Phys. Rev.

K10. Vacuum Ultraviolet Optical and Photoelectric Properties of Evaporated Metal Films.* W. C. WALKER,† O. P. RUSTGI, AND G. L. WEISSLER, *University of Southern California.*—Measurements of optical and photoelectric properties of metal films have been made in order to obtain more information about the volume photoelectric effect[1] and to find correlations with observed electron energy eigenlosses.[2] Al, Sn, In, Bi, Ag, Au, and Cd have been investigated. Data covering the spectral region from 452 A to 1623 A on reflectivities and photoelectric yields of films evaporated "in situ," together with transmissivities of unbacked films, will be presented. Regions of transparency have been observed in Al, Sn, In, and Bi. The onset in Al (14.6 ev) and In (11.1 ev) agrees with the free electron plasma energy, whereas that for both Sn (13.6 ev) and Bi (18.0 ev) is shifted somewhat from the expected values of 12.0 ev and 14.0 ev. Interband absorption edges lying within the transmission region were observed in Sn at 24.0 ev, In at 16.8 ev, and Bi at 23.9 ev. No transmission greater than 0.3% was observed for Au, Ag, or Cd over the spectral region studied. Correlation between the optical and the photoelectric data, together with observed eigenlosses and theoretical plasma frequencies, will be presented.

* The continued support of the O.O.R. is gratefully acknowledged.
† Present address, Physical Sciences Department, University of California, Santa Barbara.
[1] Walker, Wainfan, and Weissler, J. Appl. Phys. 26, 1366 (1955).
[2] L. Marton and L. B. Leder, Phys. Rev. 94, 203 (1954).

K11. Determination of a Screw Dislocation Direction in *W* by Field Emission Microscopy.* R. W. STRAYER, *Linfield Research Institute.*—The direction of screw dislocations in *W* crystals has been investigated by field emission techniques. Drechsler, employing an ion microscope, has reported evidence for a ⟨110⟩-directed screw dislocation.[1] Evidence of a ⟨111⟩-directed screw dislocation is reported here. On the emission pattern of a heated field emitter, the average ratio of spiral revolutions observed on the (101) plane to number of collapsing rings[2] observed on the (110) plane was essentially the same as the ratio of collapsing rings observed on the two planes. The spiral is assumed to result from emission from the step edge of a screw dislocation intersecting a crystal surface plane; each spiral revolution is assumed to correspond to removal of a layer of tip material equivalent to the minimum step height. A collapsing ring has been shown previously to correspond to the dissolution of a single atom layer.[3] It will be shown that the above comparison indicates equal spiral and ring step heights. Possible dislocation orientations yielding this result are the ⟨111⟩ directions.

* This work was supported by the Office of Naval Research.
[1] M. Drechsler, Z. physik Chem. 6, 272 (1956).
[2] Trolan, Barbour, Martin, and Dyke, Phys. Rev. 100, 1646 (1955).

TUESDAY AFTERNOON AT 2:00

Chemistry 2276

(J. W. ELLIS presiding)

Resonance Physics and Other Topics

L1. Isotope Shifts and Hyperfine Structures in the Spark Spectrum of Tellurium. H. G. KUHN AND R. TURNER, *Clarendon Laboratory.*—The isotope shift in the line λ4049 of of TeII ($5s5p^4\ ^4P_1 - 5s^25p^26p_1$) was measured interferometrically for the 6-even and 2-odd stable isotopes. Enriched samples* were used in a hollow cathode discharge cooled with liquid oxygen. The following wave-number differences were found; for the even isotopes: 22.7±1.2, 21.5±0.4, 17.3±0.4, 16.7±0.4, 14.5±0.5 mK for 122–120, 124–122, 126–124, 128–126 and 130–128, respectively; for the odd-odd and odd-even shifts: 21.0±1.6 mK for 125–123, and −1.5±1.5 mK for 123–122 and 125–124; i.e., the staggering effect is so large that the order of mass numbers is just reversed. The ratio of the hf splittings of 125 and 123 was found to be 1.195. This

is slightly smaller than the ratio 1.2056 of the magnetic moments,[1] but the difference is scarcely larger than our estimated limits of error. Some of our results differ appreciably from those found by Ross and Murakawa.[2]

* The samples were supplied and the work was partially supported by the A.E.R.E. Harwell.
[1] S. S. Dharmatti and H. E. Weaver, Phys. Rev. **84**, 843 (1951).
[2] J. S. Ross and K. Murakawa, Phys. Rev. **85**, 559 (1952).

L2. Nuclear Spin, Hyperfine Structure Separation and Magnetic Moment of Potassium-43.* F. RUSSELL PETERSEN, VERNON J. EHLERS, W. BRUCE EWBANK, LAWRENCE L. MARINO, AND HOWARD A. SHUGART, *University of California, Berkeley.*—With the atomic beam magnetic resonance technique, the nuclear spin of 22-hr K^{43} has been measured as $\frac{3}{2}$. The isotope is collected on a sulfur-coated surface[1] and beta-counted in continuous flow proportional counters. An initial search was conducted on the usual flop-in transition ($F=2$, $M_F=-1\leftrightarrow-2$) at low magnetic fields.[2] At higher values of the field, the quadratic shift of frequency of this line yields a sufficiently good value of the hyperfine structure constant to permit a search for direct transitions between the $F=2$ and $F=1$ levels. Of the 6 observable transitions of the $\Delta F=1$ type, the $M_F=0\leftrightarrow0$, $1\leftrightarrow0$ doublet and the $-1\leftrightarrow0$ doublet transitions have been observed. A preliminary hyperfine structure separation of 192.6±0.2 Mc/sec for the $^2S_{\frac{1}{2}}$ electronic ground state is obtained. Through use of the Fermi-Segrè formula and K^{39} as a reference isotope, the magnetic moment becomes $\mu_I=\pm.163\pm.002$ nm. The radioisotope was prepared by $A^{40}(\alpha,p)K^{43}$ reactions with 20-Mev alpha particles from the Berkeley 60-in. cyclotron. The alpha energy is initially degraded from 47 Mev to reduce the production of K^{42} through the α, pn reaction. Stable potassium serves as carrier for the radioisotope and is used to calibrate the homogeneous C field.

* This research was supported by the Air Force Office of Scientific Research and the U. S. Atomic Energy Commission.
[1] Hobson, Hubbs, Nierenberg, Silsbee, and Sunderland, Phys. Rev. **104**, 101 (1956).
[2] J. R. Zacharias, Phys. Rev. **61**, 270 (1942).

L3. Spin and Magnetic Moment of 300 Day Mn^{54} by Dynamic Nuclear Polarization. R. W. KEDZIE AND C. D. JEFFRIES, *University of California, Berkeley.**—Saturation[1] of the forbidden and allowed lines of the paramagnetic resonance spectrum of 300-day Mn^{54} produces an anisotropy in the emitted gamma rays which is detected. This experiment is similar to the Co^{60} [2] and Mn^{52} [3] experiments which were reported previously. Approximately 0.1 mc of Mn^{54} and 75 μg of Mn^{55} were grown into a 300 mg single crystal of $La_2Mg_3(NO_3)_{12}\cdot24D_2O$ and placed in the microwave cavity of a paramagnetic resonance apparatus operating at 9200 mc and 1.8°K. The gamma-ray pattern is complicated by the fact that $4I$ lines due to the two sets of forbidden lines $\Delta(M_s+M_I)=0$, 2 appear in each hyperfine group. From these data we are able to measure the spin, $I=3$, and the nuclear (g) factor ratio $g(Mn^{54})/g(Mn^{55})$ which yields the magnetic moment of Mn^{54}: $\mu^{54}=3.30\pm0.06$ nm.

* Supported in part by the U. S. Atomic Energy Commission.
[1] A. Overhauser, Phys. Rev. **92**, 411 (1953); A. Abragam, Phys. Rev. **98**, 1729 (1955); C. D. Jeffries, Phys. Rev. **106**, 164 (1957).
[2] Abraham, Kedzie, and Jeffries, Phys. Rev. **106**, 165 (1957).
[3] Abraham, Jeffries, Kedzie, and Leifson, Bull. Am. Phys. Soc. Ser. II, 382 (1957).

L4. Hyperfine Structure of Rb^{86}.* N. BRASLAU, G. O. BRINK, J. M. KHAN, AND J. D. FAUST, *University of California, Berkeley.*—A preliminary remeasurement of the hyperfine structure of 18.6 d Rb^{86} has been made by the atomic beam magnetic resonance method. The hfs was first measured by Bellamy and Smith,[1] who obtained a value of 3960±20 mc. Observation of the $(\frac{1}{2},\frac{1}{2})\rightarrow(\frac{3}{2},\frac{1}{2})$ transition at fields of 184 and 630 gauss result in a value of 3948.7±2 mc. The beam was detected by collection on sulfur-coated bottons which were counted in scintillation counters. The isotope was obtained from Oak Ridge in the form of RbCl in HCl, which was loaded into the oven as a dry salt with an excess of calcium metal. A steady beam was produced on heating the oven to several hundred degrees Centigrade. This work constitutes the first hfs measurement on a machine designed to investigate the hyperfine-structure anomalies of a series of radioactive cesium and rubidium isotopes. The machine has several interesting features which will be discussed.

* Supported by the U. S. Atomic Energy Commission and the U. S. Office of Naval Research.
[1] E. H. Bellamy and K. F. Smith, Phil. Mag. **44**, 33 (1953).

L5. Microwave Spectrum and Internal Rotations of $CH_3C\equiv CCH_2Cl$. VICTOR W. LAURIE* AND DAVID R. LIDE, JR., *National Bureau of Standards.*—The microwave spectrum of 1-chlorobutyne has been investigated in the region from 15–30 kmc. The existence of nearly free internal rotation of the methyl group gives rise to regions of very dense absorption. Rotational constants for the ground torsional state of the Cl^{35} species are: $b_0=1490.55$ Mc, $c_0=1385.06$ Mc, $a_0-(b_0+c_0)/2=16\,190$ Mc, $D_{JK}=-28.4$ Kc, $D_J=0.40$ Kc. Transitions for the Cl^{37} species have also been measured. From the rotational constants an upper limit of 100 cal/mole may be established for the potential barrier hindering internal rotation. This may be compared with the value 3560 cal/mole found[1] in ethyl chloride.

* National Research Council, National Bureau of Standards Research Associate, 1957–1958.
[1] D. R. Lide, Jr., J. Chem. Phys. (to be published).

L6. Hyperfine-Structure Splitting of Thallium-204.* J. WINOCUR, R. MARRUS, J. C. HUBBS, AND A. CABEZAS. *University of California, Berkeley.*—The atomic-beam magnetic-resonance method has been used to measure the field-independent transitions ($F=\frac{1}{2}$, $m=\pm\frac{1}{2}\leftrightarrow F=\frac{3}{2}$, $m=\mp\frac{1}{2}$) in 4.1-yr Tl^{204} ($I=2$). The result is $\Delta\nu(^2P_1)=730.837\pm0.005$. The corresponding nuclear magnetic moment not including hfs anomaly correction is ±0.0893. This experiment is a continuation of previous investigations[1] and represents an improvement by a factor of 10^2 in the accuracy of $\Delta\nu$.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] Brink, Hubbs, Nierenberg, and Worcestor, Phys. Rev. **107**, 189 (1957).

L7. Hyperfine Structure of Trapped Hydrogen Atoms. R. BERSOHN,* *Cornell University.*—Hydrogen atoms have been produced in the solid state and observed by means of paramagnetic resonance by Livingston and Jen *et al.* The hyperfine structure splitting varies but is typically 0.5% less than the celebrated value for the isolated atom. Our interest is to investigate the origin of the change in the hfs. The forces acting on the electron are assumed to be derivable from an averaged potential which is a function only of the position of the electron. The noncentral part of the potential can be neglected because it modifies the electron density at the nucleus only in second order. Assuming that the central potential, $V(r)$ acting on the electron is expandable in a power series in r, an exact expression is derived for the first order perturbed wave function in terms of the coefficients of the potential development. One can now obtain a rough idea of the sort of potential necessary to explain the experimental data. This same method is being used to study the shift of hyperfine frequency of H and alkali atoms with added buffer gas.

* Supported by the U. S. Atomic Energy Commission.

L8. Electron Spin Relaxation Times in Phosphorous-Doped Silicon. G. FEHER AND E. A. GERE, *Bell Telephone Laboratories.*—The relaxation processes connecting the four energy levels in P-doped silicon were investigated at ~9000 Mc/sec. The relaxation time $T_s(\Delta m_s=\pm1,\ \Delta m_I=0)$ at 1.2°K was inde-

pendent of the phosphorous concentration below $\sim 10^{16}$ P/cm³. Its value at 1.2°K was $\sim 3\times 10^{+3}$ sec. Above 10^{16} P/cm³ T_s varied rapidly with donor concentration dropping to 10^{-4} sec at 3×10^{17} P/cm³. In the concentration dependent region T_s was independent of temperature ($1.2°K < T < 3°K$) and magnetic field ($3000\Phi < H < 8000\Phi$). In the concentration independent region T_s varied as $1/T$ for $1.2°K < T < 2°K$ and $1/T^7$ for $2.5°K < T < 4.2°K$, suggesting a transition from a direct to Raman type process. The relaxation time $T_s(\Delta m_s = \pm 1, \Delta m_I = \mp 1)$ was ~ 30 hours at 3000Φ (1.2°K) and ~ 5 hours at 8000Φ in fair agreement with theory.[1] The relaxation time $T_N(\Delta m_I = \pm 1, \Delta m_s = 0)$ at 1.2°K exceeded 10 hr. The effect of light on the relaxation times[2,3] was investigated for $0.6\mu < \lambda < 3\mu$. The largest reduction in T_s was found at a wavelength corresponding to the band gap. The existence of an effect at longer wavelengths indicates the importance of impurity ionization.

[1] Pines, Bardeen, and Slichter, Phys. Rev. **106**, 489 (1957).
[2] G. Feher and R. C. Fletcher, Bull. Am. Phys. Soc. Ser. II, **1**, 175 (1956).
[3] A. Honig, Kamerlingh Onnes Low Temperature Conference (1958).

L9. Antiferromagnetic Resonance in FeF_2.* R. C. OHLMANN† AND M. TINKHAM, *University of California, Berkeley.*—Employing far-infrared techniques, a field-free antiferromagnetic resonance has been observed in FeF_2. The resonance occurs at 53 cm^{-1} at temperatures up to 15°K, and it shifts appreciably toward lower frequencies with further increase in temperature. The anisotropy constant, K, may be obtained from this frequency using the resonance relation derived by Nagamiya,[1] and by Keffer and Kittel.[2] This may be written $\omega = \gamma(2K/\chi_\perp)^{\frac{1}{2}}$, where $\chi_\perp$ is the perpendicular susceptibility. Taking $g_{\parallel} = 2.24$, as obtained from paramagnetic resonance data,[3] and a molar susceptibility[4] $\chi_\perp = 15.9\times 10^{-4}$, we obtain an anisotropy energy of 17.3 cm^{-1} per atom of Fe^{2+}. This may be compared with the value 22 cm^{-1} which may be estimated from measurements of the temperature dependent anisotropy of the paramagnetic susceptibility.[3]

* Supported in part by the Alfred P. Sloan Foundation, the Office of Naval Research, and the National Science Foundation.
† Westinghouse Research Laboratories Fellow.
[1] T. Nagamiya, Progr. Theoret. Phys. (Kyoto) **6**, 350 (1951).
[2] F. Keffer and C. Kittel, Phys. Rev. **85**, 329 (1952).
[3] M. Tinkham, Proc. Roy. Soc. (London) **A236**, 535 (1956).
[4] J. W. Stout and L. M. Matarrese, Revs. Modern Phys. **25**, 338 (1953).

L10. Observation of Microwave Faraday Rotation in MnF_2.* DALE TEANEY AND A. M. PORTIS, *University of California, Berkeley.*—Microwave Faraday rotation has been observed in MnF_2 between 25°K and 300°K. The most striking characteristic of the data is the increase in the rotation by nearly three orders of magnitude as the temperature of the sample is raised above the Néel point. The measurements were made on a single crystal of MnF_2[1] cemented to the end wall of a bimodal transmission cavity.[2] The detection of antiferromagnetic Faraday rotation is made possible by the exceptional stability of the bimodal cavity. The sample was oriented so that the c axis of the sample coincided with the symmetry axis of the cavity. The filling factor of the sample in the cavity was determined from rotation measurements in the paramagnetic range. From this information and an analysis of the response of the bimodal cavity values of the off-diagonal elements of the susceptibility tensor are obtained as a function of temperature.

* Supported in part by the Office of Naval Research, the Signal Corps, the National Security Agency, and the Air Force Office of Scientific Research.
[1] The sample used in these measurements was obtained from the Bell Telephone Laboratories through the courtesy of A. M. Clogston.
[2] A. M. Portis and D. Teaney, J. Appl. Phys. **29** (to be published).

L11. Theory of Microwave Faraday Rotation in MnF_2.* A. M. PORTIS, *University of California, Berkeley.*—Microwave Faraday rotation in antiferromagnetics was predicted theoretically by Wangsness,[1] who obtained an expression for the rotation to be expected at $T = 0°K$. We have extended this treatment to higher temperatures and compared the results with experiment. An equation of motion is used which below the transition has the form introduced by Kittel. Above the transition the equations go over onto the familiar Bloch form. Below the transition in the limit of small fields and at frequencies well below the antiferromagnetic resonance frequency we find that the off-diagonal element of the susceptibility tensor, $\chi_{xy} = 2i\omega\gamma H_0(\chi_\perp - \chi_{\parallel})/\omega_0^2$, where ω_0 is the zero-field antiferromagnetic resonance frequency.[2] There is generally good agreement between experiment and the predicted curves except in the immediate vicinity of the transition. In particular the decrease in rotation by three orders of magnitude, which is expected as the material becomes antiferromagnetic, takes place over a 10° range of temperature. It does not appear that the temperature dependence in this range can be understood in terms of a simple resonance equation but requires an investigation of the spectrum of excited states.

* This research was supported in part by the Office of Naval Research, the Signal Corps, the National Security Agency, and the Air Force Office of Scientific Research.
[1] R. K. Wangsness, Phys. Rev. **95**, 339 (1954).
[2] F. M. Johnson and A. H. Nethercot, Jr., Phys. Rev. **104**, 847 (1956).

L12. Faraday Effect in Metals.* EDWARD A. STERN AND RALPH D. MYERS, *University of Maryland.*—The rotation of the plane of polarization of light reflected normally from a nonferromagnetic metallic surface that has a magnetic field perpendicular to it is shown to be expected from theoretical grounds. This effect in a ten thousand gauss field is about one thousand times smaller than the corresponding magneto-optic-Kerr effect in ferromagnetic materials. From symmetry arguments this Faraday effect for cubic metals is independent of the orientation of the crystal axes to the surface normal. However, it does depend on an average effective mass of the valence band electrons and thus can be used to measure this effective mass. Experimental values of this effective mass will be given for a few metals whose Faraday effect has been measured. Since only an average effective mass is measured by the Faraday effect, no detailed information on the shape of the Fermi surface can be directly obtained by this means. However the technique can be used at practically any temperature and with alloys and thus can give information on those metals whose band structure can't be easily studied by other techniques.

* Supported by the National Security Agency and the U. S. Air Force Office of Scientific Research.

L13. Observation of Cyclotron Resonance in Copper.* D. N. LANGENBERG,† A. F. KIP, AND B. ROSENBLUM, *University of California, Berkeley.*—An Azbel-Kaner type cyclotron resonance has been observed in a sample of natural copper. Fundamental and subharmonic resonance minima of order $q = 1, 2, 3, 4$ were observed superimposed on a monotonically decreasing surface resistance with a form qualitatively like $R(H) = R(0)\tanh^{\frac{1}{2}}A/H$. The resonance was observed only near particular sample orientations, and in the region of observability the cyclotron mass was essentially independent of orientation. The agreement between the experimental resonance curve and a theoretical curve calculated using $\omega\tau = 10$ is satisfactory and gives a cyclotron mass $m^*/m_e = 1.37 \pm 0.05$. This mass is consistent with estimates of extremal cyclotron masses calculated from Moliner's analytical expression for Pippard's Fermi surface.[1,2] No phase shift between experimental and theoretical curves like that reported by Aubrey and Chambers is present.[3]

* Research supported in part by the Office of Naval Research, the Signal Corps, the Air Force Office of Scientific Research, and the National Security Agency.
† National Science Foundation Predoctoral Fellow.
[1] F. G. Moliner, Phil. Mag. **3**, 207 (1958).
[2] A. B. Pippard, Phil. Trans. Roy. Soc. (London) **A250**, 325 (1957).
[3] J. E. Aubrey and R. G. Chambers, J. Phys. Chem. Solids **3**, 128 (1957).

L14. Pressure Effects of He and A on the First Sharp Series Doublet of Indium.* SHANG YI CH'EN AND ALLEN SMITH, *University of Oregon* (introduced by R. T. Ellickson).—In contrast to the much studied pressure broadenings and shifts of alkali doublets with ^2S as ground state, the first sharp series doublet of In (λ4101 and λ4511) allows the study of the perturbation of energy levels whose fine structure separation is due to the ground states ^2P. The line contours, the shifts, and the satellites of these lines were studied for pressures up to 120 atmos of He and A with a 35-ft grating. The half-width in cm^{-1}/rd are respectively 1.23 and 1.10 A, and 1.13 and 1.18 for He. The shift increases approximately with the 1.3 power of rd. By taking the ratios of $\Delta\omega_m/\Delta\omega_1$ according to Anderson's equation[1] from the data for A, one is led precisely to a force law of Van der Waals' type, and an optical collision diameter of 7.92 A and 8.33 A for the two lines, respectively. The f values determined from the amount of total absorption by graphical integration of the line contours are respectively 0.07 and 0.15.

* Sponsored by the Office of Ordnance Research, U. S. Army.
[1] S. Ch'en and M. Takeo, Revs. Modern Phys. **29**, 42 (1957), Eq. 130.

TUESDAY EVENING AT 7:30

Miramar Hotel, Santa Monica

(J. W. BEAMS presiding)

Banquet of the American Physical Society

After-Dinner Speech

Some Comments on Present Day Physics. H. C. UREY, *University of California.*

WEDNESDAY MORNING AT 10:00

Franz Hall 104

(D. S. SAXON presiding)

Invited Papers on Theoretical Physics

M1. π-e Decay. R. J. FINKELSTEIN, *University of California, Los Angeles.* (30 min.)

M2. Electromagnetic Structure of Elementary Particles. S. D. DRELL, *Stanford University.* (30 min.)

M3. Unstable Particles as Targets in Scattering Experiments. G. F. CHEW, *University of California, Berkeley.* (30 min.)

M4. Review of Recent Work on Analyticity Properties of Propagation Functions. A. S. WIGHTMAN, *Princeton University.* (30 min.)

WEDNESDAY MORNING AT 9:30

Chemistry 2276

(K. R. MACKENZIE presiding)

Low-Energy Nuclear Physics

N1. Detailed Balance in the Reactions $p+T \rightleftarrows D+d$ and Differential Cross Sections for the $He^3(n,d)H^3$ Reaction.* J. N. BRADBURY† AND L. STEWART, *Los Alamos Scientific Laboratory.*—With the measurement of the $H^3(p,d)H^2$ cross section at a proton energy of 8.3 Mev,[1] it becomes possible to compare the ratio of the cross sections of the reciprocal reactions $d+D \rightleftarrows T+p$ with that predicted on the basis of detailed balance. The calculated and experimental ratios are found to agree within limits of experimental error in accord with results on other reactions.[2] The validity of detailed balance here makes it reasonable to apply a similar calculation to the mirror-reaction pair, $n+He^3 \rightleftarrows H^3+d$. Accordingly, the $He^3(n,d)H^3$ cross sections are calculated on the basis of data available for the inverse reaction at He excitation energies of 25.1, 26.6, 28.1, 29.6, and 31.1 Mev.

* Work supported by the U. S. Atomic Energy Commission.
† Now located at the Department of Physics, Stanford University.
[1] J. E. Brolley, Jr. and L. Rosen (private communication).
[2] J. H. Coon, Phys. Rev. **80**, 488 (1950); Burcham, McCauley, Bredin, Gibson, Rotblat, and Prowse, Nuclear Phys. **5**, 141 (1958); and Bodansky, Eccles, Farwell, Rickey, and Robinson, Bull. Am. Phys. Soc. Ser. II, **3**, 327 (1958).

N2. Inelastic Scattering of Protons and the 3^- State of Pb^{208}.* T. TAMURA AND D. C. CHOUDHURY, *University of California, Los Angeles.*—In our previous paper[1] the data of

Cohen and Rubin on the inelastic scattering of protons by Pb-isotopes and other nuclei were analyzed. It was found that the theory of direct interaction with the plane wave approximation could well explain the experimental results on the relative magnitude of the excitation of various states. In particular the anomalous peak at $-Q=2.6$ Mev in the Pb isotopes was considered as due to the proton transition, $(d_{3/2})\rightarrow(h_{9/2})$, which is commonly considered to explain the 3^- states of Pb^{208}. The lifetime of this state is, however, at least five times shorter than that expected from the above single-particle transition.[1] This discrepancy can be approximately accounted for if an octupole-octupole force is assumed, (an extension of the quadrupole-quadrupole force of Elliott) as it is then found that all the configurations mixed by this force add constructively to the transition amplitude. Using this new wave function for the 3^- state and the distorted wave approximation, a more refined calculation of the inelastic scattering is now in progress.

* Partially supported by the Office of Ordnance Research.
[1] T. Tamura and D. C. Choudhury (submitted to Phys. Rev.).

N3. Analysis of Elastic Cross Sections and Polarization of 10 Mev Protons.* J. S. NODVIK† AND D. S. SAXON, *University of California, Los Angeles.*—The differential elastic cross sections and polarization of 10 mev protons scattered by argon and copper[1] have been analyzed[2] using a diffuse surface optical model potential with a spin-orbit term. The model parameters were varied systematically, the best fits with the experimental data being determined by a method of least squares. As in other analyses, it was found that almost equally good fits could be obtained over a range of values of the radius constant R_0, in this case, for R_0 approximately between 1.18 and 1.28. Only the value of the real part of the central potential was markedly different for the best fits obtained for various R_0 in this range. The experimental polarization data was not precise enough to determine the spin-orbit potentials to within better than approximately 2 Mev. Detailed comparisons between calculated and observed cross sections will be presented.

* Research supported in part by the National Science Foundation, the Office of Naval Research, and the Office of Ordnance Research.
† Now at the University of Southern California.
[1] We are indebted to L. Rosen for furnishing his results prior to publication.
[2] The calculations were performed on the SWAC, Numerical Analysis Research Project, Department of Mathematics, U.C.L.A.

N4. $C^{13}(p,n)N^{13}_{\text{ground state}}$ Excitation Function from 3 to 11.5 Mev.* S. D. BLOOM, R. M. LEMMON, AND S. A. MOSZKOWSKI,† *University of California, Livermore and Berkeley.*—The excitation function for the production of $N^{13}_{\text{ground state}}$ from C^{13} via proton bombardment has been measured from threshold (3.21 Mev) up to 11.5 Mev using a thin gas target of C_2H_2 enriched to 67% in C^{13}. The impetus for this work was provided by the fact, noted by D. H. Wilkinson,[1] that all states except the ground state of N^{13} are unstable to proton emission. Thus in the present investigation one is observing a process in which the final nuclear state is not only single and well defined, but also the charge-mirror image of the initial nuclear state. If this process can be explained as a consequence of a direct interaction mode, the simplifications made possible by the above situation can lead to correspondingly simplified predictions for the behavior of the cross section as a function of energy and angle. Preliminary data obtained on the Livermore 90-in. cyclotron show a total cross section rising immediately above threshold rather more slowly than a first-version direct-interaction theory would predict. The fall-off at higher energies, however, corresponds roughly to theory.

* Work done under the auspices of the U. S. Atomic Energy Commission.
† University of California of Los Angeles, Los Angeles, California.
[1] D. H. Wilkinson, Phys. Rev. 100, 32 (1955).

N5. Elastic Scattering of Protons from Li^6.† JAMES A. MCCRAY, *California Institute of Technology.*—The elastic scattering of protons from Li^6 nuclei has been studied as a function of both angle and energy from 0.45 to 1.8 Mev. The elastic scattering cross section approaches the Rutherford value near 0.45 Mev and clearly shows the anomaly reported by Bashkin and Richards[1] at about 1.75 Mev. The elastic scattering at a laboratory angle of 156° shows no marked anomaly corresponding to the structure near 1 Mev in the excitation curve of the $Li^6(p,He^3)He^4$ reaction.[2] Excitation curves and angular distributions will be presented.

† Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] S. Bashkin and H. T. Richards, Phys. Rev. 84, 1124 (1951).
[2] See, for example Marion, Weber, and Mozer, Phys. Rev. 104, (1956).

N6. General Design of a Spiral Cloverleaf Cyclotron.* J. REGINALD RICHARDSON, *University of California, Los Angeles.*—A recently constructed 40-ton magnet is being converted to the production of the azimuthally varying field appropriate to a constant frequency cyclotron which will accelerate protons to 50 Mev. A simplified theory appropriate to step function magnetic fields has been developed and modified to the extent required by the physically realized fields. Fourfold symmetry with constant angular width of the hills (or valleys) has been chosen. The vertical axial frequency then becomes $\nu_z^2=-(\beta^2/1-\beta^2)+F[A+(A+D)\tan^2\gamma]$, where γ is the spiral angle and A and D are constants for this particular design. F is defined in another paper at this session. The field is of the Thomas type ($\gamma=0$) out to about half of the final radius. The hill field is 25 000 gauss and valley field is 16 570 gauss at the final radius where $\gamma=48°$. The total angle of turning of the spirals is 27°. Final adjustments on the isochronous condition will be made on the beam by adjustment of eight circular concentric pairs of trimming coils. Calculations indicate that these should give a threshold energy gain per turn of 40 kev.

* Supported in part by the Joint Program of the Office of Naval Research and the U. S. Atomic Energy Commission.

N7. Spiral Ridge Cyclotron Magnetic Field Measurements.* DAVID J. CLARK AND BYRON T. WRIGHT, *University of California, Los Angeles.*—The U.C.L.A. 50-Mev spiral ridge cyclotron is made of SAE 1010 steel. It has a pole tip diameter of 46½ in. and an air gap of 6 in. In each of 4 alternate octants are placed two 1½-in. thick iron sectors whose sides are bounded by straight lines from the center to a 9-in. radius, and by spiral curves from 9 to 22½ in. These prisms are spaced about ½ in. away from the pole tips. The air gap between two prisms in an octant is 2 in. at a 5-in. radius, and 1 in. at a 22½-in. radius. The "valley" gap varies from 6 in. near the center to 4 in. at the edge. Shimming on "hills" and "valleys" has thus far produced fields within 2% of the desired values. The present magnet power is 105 kilowatts. We define a flutter factor as: $F=1-b/45°$. b is the azimuthal angle over which the field changes from $(B_v+0.15h)$ to $(B_v+0.85h)$, where B_v is the valley field and h is the total valley to hill variation. ($F=1$ for a step-function field variation and $F=0.5$ for a sine wave variation.) The measured flutter factor varies from 0.55 at a 3-in. radius to 0.9 at the edge.

* Supported in part by the Joint Program of the Office of Naval Research and the U. S. Atomic Energy Commission.

N8. Spiral Dee rf System. K. R. MACKENZIE, *University of California, Los Angeles.**—Beam extraction, flutter and economy dictate gaps over the ridges about equal to the height of the beam. No room can be spared for dees. They must be placed in the valleys, and it is gratifying to find this is beneficial. Gaps are large, and angular widths are small. Capacities are low and high voltages come easily. Given voltage gains per turn can be realized with less power and less predicted spark-

ing than with conventional dees. Alternate valleys are employed leaving two available for other purposes. The frequency range is approximately 25 to 30 Mc. For future consideration, dee in valley systems of greater mechanical complexity have been studied. Use of a modified barn door, in which the conductor surface varies inversely as the reduction in impedance, results in approximately constant power over the range. With mechanical compromises it appears that a 3 to 1 range would about double the present 30 kw for 40 kv per turn. The power increase is roughly proportional to the range desired.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

N9. Elastic Proton Scattering by the Separated Isotopes of Zn.* ROGER W. BOOM† and J. REGINALD RICHARDSON, *University of California, Los Angeles.*—The differential cross sections for the elastic scattering of 20.35±0.25 Mev protons by enriched Zn^{64}, Zn^{66}, and Zn^{68} have been measured for scattering angles between 30° and 160°. Zn^{68} is noticeably different at small angles. The shift of the position of the first minimum near 60° is in the expected direction and it amounts to about 1 degree for two units change in nuclear mass. The second minimum is near 100° and here the shift is about 1.4° for a mass change of two units. These isotope shifts are in reasonable agreement with the elementary picture of potential scattering. The third minimum in the scattering cross section occurs near 141° and here the isotope shift is quite small. Although much less certain, the shift appears to be in the opposite direction from that of the other two minima. There is no large isotopic change in the magnitude of the scattering cross sections for the first and second minima. However, for the third minimum, the magnitude of the cross section increases by over a factor of two in going from Zn^{68} to Zn^{64}. Preliminary theoretical calculations by David Saxon and John Nodvik indicate the probability of obtaining a good theoretical fit.

* Supported in part by the Joint Program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at the Institute of Nuclear Physics, University of Bonn, Federal German Republic.

N10. α-α and α-He^3 Scattering. REN CHIBA, H. E. CONZETT,* H. MORINAGA, N. MUTSURO, K. SHODA, AND M. KIMURA, *Tohoku University.*—Scattering of α particles by He^4 and He^3 have been investigated with an α-particle beam from a variable-energy cyclotron at the Institute for Nuclear Study of the University of Tokyo. He^4 and He^3 gases were filled in target chambers which were placed at the center of a 1-meter scattering chamber. Scattered particles were observed by a CsI scintillation counter and a 20-channel analyzer. Spectra were observed every 2 or 2.5 degrees and angular resolution was less than one degree. Angular distributions of scattered α's from He^4 have been measured at bombarding energies of 32.5 Mev and 35.5 Mev. The patterns were essentially the same as those obtained by Birmingham group using emulsions. Angular distributions of $\alpha-He^3$ scattering were obtained from the peaks due to scattered α and recoil He^3. At most of the angles they were separable, and thus the distributions from 35° to 150° c.m. have been investigated at the bombarding energies of 27.5, 28.5, 29.4, 30.0, and 32.0 Mev. The c.m. differential cross sections show three distinct minima at 47°, 96°, 135°. No remarkable difference was observed in the angular distribution in this energy range. The breakups into Li^6 and proton were also observed.

* Fulbright Exchange Research Scholar at University of Tokyo.

N11. $T(p,p)T$ Scattering near the $T(p,n)He^3$ Threshold.* NELSON JARMIE AND ROBERT C. ALLEN,† *Los Alamos Scientific Laboratory.*—Differential scattering cross sections for the scattering of protons bombarding a gaseous tritium target have been measured near the $T(p,n)He^3$ threshold (1.019 Mev). The experimental equipment has been described previously.[1] Measurements were taken for proton energies from 0.7 to 1.4 Mev at lab angles of 45° and 90° (58.5° and 109.5° in the c.m. system), and the absolute values are in fair agreement with previous work.[2] The 45° data show a small but definite convex "cusp" around threshold. The 90° data have a less definite but distinct break at threshold. Such perturbations have been predicted[3] and their analysis should lead to information on the phase shifts of the scattering. The bearing of the data on a possible excited state in He^4 at 20 Mev will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Now at Atomics International, Canoga Park, California.
[1] N. Jarmie and R. C. Allen, Phys. Rev. 111, 1121 (1958).
[2] M. E. Ennis and A. Hemmendinger, Phys. Rev. 95, 772 (1954).
[3] For information on this subject and a guide to other references see G. Breit, Phys. Rev. 107, 1612 (1957) and A. I. Baz', Soviet Phys. JETP 6, 709 (1958).

N12. Gamma Radiation from the Proton Bombardment of Potassium. R. D. SHARP, R. M. FRIEDMAN, AND L. F. CHASE, JR., *Lockheed Missile Systems Division.*—Thin targets of natural potassium metal and potassium iodide have been bombarded with protons of energies up to 3.5 Mev from the Lockheed Van de Graaff generator. Gamma rays of 0.440, 0.625, 1.00, 1.27, 1.65,* and 2.16 Mev have been observed. Charged particle-gamma ray coincidence experiments at 3.04 Mev have shown that the 2.16-Mev gamma ray results from a $(p,\alpha\gamma)$ reaction in K^{41} (natural abundance 6.8%) and that the 1.00, 1.65, and probably the 1.27-Mev gamma rays arise from inelastic proton scattering in K^{41}. The excitation functions of the two most intense gamma rays (1.00 and 2.16 Mev) have been studied and several prominent resonances corresponding to states in Ca^{42} have been observed.

* Mean energy of several unresolved gamma rays.

N13. Ranges of Heavy Ions in Emulsion.* HARRY H. HECKMAN, B. L. PERKINS, FRANCES M. SMITH, AND WALTER H. BARKAS, *University of California, Berkeley.*—The range-energy relations for C, N, O, Ne, and A in Ilford C.2 nuclear track emulsion have been determined. The ions, accelerated to 10 Mev/nucleon by the heavy-ion linear accelerator (Hilac), were allowed to pass through a small wedge-shaped degrader that served to produce a continuous momentum spectrum from 0 to P_{max}, and also a charge spectrum of the ions from net charge $Z'=0$ to the ion atomic number Z. By employing a 180° double-focusing magnetic spectrometer, we were able to record in the emulsion detectors up to six separate range groups corresponding to the discrete momentum bands (of magnitude $Z'B\rho$) that were transmitted by the spectrometer. The calibration of the instrument was accomplished by measuring the ranges of the secondary reaction products, principally alpha particles and protons, that were produced in a 10-mil Al absorber which replaced the wedge target during part of the exposure. The spectrometer had a momentum resolution of 0.1% or less with a maximum $B\rho$ of 0.91×10^4 gauss-cm. At the higher velocities, the relative ranges of the ions have been evaluated to a statistical accuracy of 0.2%. For short ranges, i.e., 1 to 10 μ, the resolution is limited by the small range difference between adjacent charge states and by the granularity of the emulsion.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

N14. Ionization and Energy Loss of Heavy Ions in Emulsion.* WALTER H. BARKAS AND HARRY H. HECKMAN, *University of California, Berkeley.*—We have investigated the energy-loss process for heavy ions in nuclear track emulsions of various sensitivities. Beams of C, N, O, Ne, and A accelerated by the heavy-ion linear accelerator (Hilac) were used to

irradiate Ilford emulsions of types *G*.5, *C*.2, *D*.1, *K* minus 1, and *K* minus 2. The primary ionization of the ions was best studied in the least sensitive emulsion (type *K* minus 2). Here it is readily demonstrated that the primary ionization of the ions increases with decreasing velocity, rising to a maximum near the end of its range. The tapering of the ion tracks in the more sensitive emulsions is attributed to the decreasing energy of the fastest delta rays as the ion velocity is lowered, and that the mean track width has little or no correlation with the primary ionization. We have also observed buckling distortions of the tracks in regions of maximum ionization for argon ions, probably caused by strong physical development of the tracks. This effect was first observed at this laboratory by L. Muga in uranium-loaded plates which, in general, have produced larger distortions of this type than are normally observed in the unloaded emulsion. Photomicrographs demonstrating this phenomenon will be shown.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

N15. Compound-Nucleus-Formation Cross Sections for Heavy-Ion-Induced Reactions.* T. DARRAH THOMAS, *University of California, Berkeley.*—The cross section for the formation of a compound nucleus when a target is bombarded with heavy ions has been calculated for various targets, projectiles, and projectile energies using a simple model given by Blatt and Weisskopf.[1] The assumptions of this model are: (1) The nucleus has a well-defined surface, which is a sphere of radius R. (2) There is no nuclear interaction between the heavy ion and the nucleus if the distance between their centers is greater than R, and there is strong interaction if this distance is less than R. (3) $R=1.5(A_1^{\frac{1}{3}}+A_2^{\frac{1}{3}})f$, where A_1 and A_2 are, respectively, the mass numbers of heavy ion and target. (4) The kinetic energy of the particle inside the nucleus is equal to the kinetic energy outside the nucleus plus an additional amount $(K_0\hbar)^2/2M$, where M is the reduced mass of the system and $K_0=10^{13}$ cm^{-1}. (5) The logarithmic derivative of the wave function of the incoming particle, $f_l=-iKR$, where $K^2=(k+K_0)^2$ and k is the wave number of the incoming particle outside the nucleus. The results of these calculations will be compared with experimental results. By this method it has also been possible to calculate the angular momentum distribution of the compound nucleus.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] Blatt and Weisskopf, *Theoretical Nuclear Physics* (John Wiley and Sons, Inc., New York, 1952).

N16. Study of Neutron-Proton and Proton-Proton Pairs in a Complex Nucleus Via π^- Capture†, SATOSHI OZAKI, ROY M. WEINSTEIN, AND ALBERT WATTENBERG,* *Massachusetts Institute of Technology.*—Experiments on π^- capture have been carried out in order to investigate the mechanism of this process. A pair of 11½-in. diameter, 8 in. deep, liquid neutron counters were constructed. An 11½-in. diameter proton telescope consisting of ½- and ¼-in. thick plastic disks was also made. The counters were arranged to accept two nucleons emerging back to back from the absorbing nucleus following the capture of a π^- meson. These counters (either both neutron counters, or one neutron and the proton counter) were used in conjunction with a charged particle counter which provided a signal for the incoming π meson. The coincidence counting rate of the events for (π,nn) and (π,pn) were separately measured. The data, corrected to a final approximation for the target thickness, gave a ratio of n-n to p-n coincidences of 4 ± 2, which rules out some extreme models for this process.

* Now at the University of Illinois, Urbana, Illinois.
† This work is supported by a U. S. Atomic Energy Commision contract

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WEDNESDAY MORNING AT 9:30

Chemistry 2250

(N. L. OLESON presiding)

Invited Papers on Electron Physics

O1. Negative Ion Formation in Oxygen. RONALD GEBALLE, *University of Washington.* (30 min.)

O2. Ionization Currents in Gases below Breakdown. L. H. FISHER, *New York University.* (30 min.)

O3. Photon Absorption Mechanisms and Electrical Discharges through Gases. G. L. WEISSLER, *University of Southern California.* (30 min.)

O4. Excitation of Plasma Oscillations and Propagation of Plasma Waves. ROY W. GOULD, *California Institute of Technology.* (30 min.)

O5. Waves in a Plasma in a Magnetic Field. IRA B. BERNSTEIN, *Project Matterhorn, Princeton University.* (30 min.)

WEDNESDAY MORNING AT 9:30

Chemistry 2224

(D. STORK presiding)

High-Energy Physics II

P1. Pulsed Magnetic Fields for High-Energy Particle Investigations.* Y. B. KIM AND E. PLATNER, *University of Washington.*—In the production of multihundred kilogauss pulsed fields desired in high-energy particle investigations,[1] repeated use of a conventional multiturn coil is seriously hampered by the large magnetic pressure encountered at such high fields. Taking advantage of the transient nature of the fields, one can introduce induction currents in the coil system

to transfer the magnetic pressure to the region of large mechanical strength. Practical coil configuration based on this idea is realized by inserting a rigid single turn coil (essentially a thickwall metal tubing whose circular turn is broken by a narrow slit) into a conventional multiturn coil. The current *induced* in the single turn coil is confined largely on the surface because of the skin effects and gives rise to two oppositely directed cylindrical current sheets. Such current distribution in effect causes the magnetic flux to shift toward the rigid single turn coil. The extent of this flux concentration can be controlled by shaping the single turn coil properly. Flux patterns observed for various single turn coil geometries will be presented. In essence this coil configuration is a profitable synthesis of single turn and multiturn coils and can be operated to the limit of single turn coil strength.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Y. B. Kim, Rev. Sci. Instr. 29, 680 (1958).

P2. Magnetic Quadrupole with Rectangular Aperture.* L. N. HAND AND W. K. H. PANOFSKY, *Stanford University.*—A magnetic quadrupole lens has been designed and is being built which defines the desired field shape by a current distribution on the inside faces of a rectangular box; the current emerges on one set of opposite faces and returns along the other set. The motive for such a design is the need for a quadrupole lens in a strong-focusing system where the radial excursion in the focusing plane generally greatly exceeds the excursion in the defocusing plane. The particular design of 40-in. length employs an aperture of 23>×<4 in. at a gradient of 400 gauss/in. This quadrupole in combination with a conventional 6>×<6 in. quadrupole and a bending magnet constitutes a 1 Bev/c magnetic spectrometer of 0.013-sterad aperture and a target-to-focus distance of 20 ft. It is intended to correct the aberration of the quadrupole by differential shunting of the windings.

* Supported by the joint program of the Office of Naval Research, the U. S. Atomic Energy Commission, and the Air Force Office of Scientific Research.

P3. Performance of a Double-Focusing, Zero-Dispersion Spectrometer.* R. A. ALVAREZ, K. L. BROWN, W. K. H. PANOFSKY, AND C. T. ROCKHOLD, *Stanford University.*—The spectrometer,[1] which will focus singly charged particles of momentum $p \leq 425$ Mev/c, has been constructed and tested using the Stanford Mark III linear accelerator beam as a physical ray-tracing device. The spectrometer consists of two identical magnets, $n \cong 0.27$, 110° deflecting, 30-in. radius of curvature, bending the particles in the same sense. It has been found that the double-focusing, zero-dispersion condition is obtained for particles of ~300 Mev/c momentum with both source and image positions symmetrically located 47½ in. from the magnets. This gives a useful solid angle of $\Omega_0 \sim 0.0055$ sterad for particles with central momentum p_0 originating from a point on the central axis. The solid angle does not change noticeably for particles originating from points as far as ±½ in. from the central axis. It is believed that the addition of pole-tips will increase the effective solid angle of the system. The momentum acceptance $\Delta p/p_0$ is in excess of ±4% with a useful solid angle of ~0.0015 sterad at the 4% points. For a point source and the solid angles and momentum acceptances given above, second-order aberrations prevent all particles from coming to a point focus, but 90% fall within a 2-in. diam. circle at the first-order focus.

* Supported by the joint program of the Office of Naval Research, the Atomic Energy Commission, and the Air Force Office of Scientific Research.
[1] K. L. Brown and W. K. H. Panofsky, Bull. Am. Phys. Soc. Ser. II, 1, 376 (1956).

P4. Scattering of 200-Mev Positrons by Electrons.* J. A. POIRIER, D. M. BERNSTEIN,† AND J. PINE, *Stanford University.*—A beryllium target 2 g/cm² thick was bombarded by 200-Mev positrons. A diffusion cloud chamber with a magnetic field was located behind the target and was used to detect recoil electrons from positron-electron scattering. In addition, the positron flux was measured by counting positron tracks in the chamber. About 10 000 cloud-chamber pictures have been obtained, at a positron intensity of about 60 per picture. Analysis of the pictures is in progress and the results will be presented. Attention is being concentrated on events in which the recoil electron energy is greater than 100 Mev. It is expected that about 300 such events will be seen. These events will permit a measurement of the absolute differential cross section $d\sigma/dE^-$ for positron scattering as a function of recoil electron energy E^-. The integrated cross section for E^- in the range 100–200 Mev will have a statistical uncertainty of about 6%. Systematic errors are expected to increase this uncertainty by about a factor of 2.

* Supported by the joint program of the Office of Naval Research, the Atomic Energy Commission, and the Air Force Office of Scientific Research.
† Now at Stanford Research Institute, Menlo Park, California.

P5. Photoproduction of Positive Pions in Hydrogen in the Angular Range $7° < \theta_{c.m.} < 27°$ and Photon Energy Range 220 Mev $< k <$ 390 Mev.* A. J. LAZARUS,† W. K. H. PANOFSKY, AND F. R. TANGHERLINI,‡ *Stanford University.*—Relative measurements of the cross sections for the production of positive pions by photons on protons have been carried out in the angular range $7° < \theta_{c.m.} < 27°$ for photon energies of 220, 300, 350, and 390 Mev. Positive pions were detected via the decay positron from the π-μ-e chain which was observed in a series of gates following a pulse of photons and electrons from the Mark III linear accelerator. The relative cross sections at these energies are 202±28, 168±23, 246±37, and 395±90, in arbitrary units. The angular distribution in the range indicated above is uniform within ±7% statistics. The results have been compared with new dispersion theory calculations using a range of values of the coupling constant and resonance energy. The experimental data at these small angles are in good agreement with the calculations; however, the fit of the calculations with available data at larger angles is not satisfactory. It is shown that the fit in either case is substantially poorer if the so-called "retardation term," i.e., the diagram in which the photon is absorbed by a virtual meson, is omitted.

* Supported by the joint program of the Office of Naval Research, the Atomic Energy Commission, and the Air Force Office of Scientific Research.
† Now at RAND Corporation.
‡ Now at the Institute for Theoretical Physics, Copenhagen.

P6. Yield of π^0 Photomesons as a Function of Atomic Number. LESTER K. GOODWIN, JOHN D. ANDERSON, AND ROBERT W. KENNEY. *University of California, Berkeley.*—With a single gamma counter, the relative yields of photoproduced π^0 mesons from targets of Li, Be, C, N, Al, Ti, Cu, and Pb were observed as a function of the maximum energy of the bremsstrahlung beam from the 340-Mev Berkeley synchrotron. Previous measurements[1] were extended to include three laboratory-system angles. Linear least-squares fits were made to $\log(Y)$ vs $\log(A^n)$, where Y is the relative yield and A is the atomic number. The values of the slopes of the lines, n, are shown in Table I. The values of n found

TABLE I.

Lab. angle	Peak energy (Mev) 165	190	200	230	340
45°	1.77±0.10	1.40±0.11	1.37±0.22		0.80±0.03
90°	1.04±0.04	0.96±0.07		0.84±0.08	0.64±0.04
135°	1.30±0.14	0.93±0.11			0.77±0.01

at low energies and forward angles are in agreement with partial coherent production.[2,3]

[1] Anderson, Kenney, and McDonald, Phys. Rev. 100, 1798 (1955).
[2] Barringer, Meunier, and Osborne, Cern II, 282 (1956).
[3] J. Leiss and R. Schrack, Revs. Modern Phys. 30, 456 (1958).

P7. π^0 Photoproduction from Deuterium in the Bev Range.* H. H. BINGHAM, *California Institute of Technology* (introduced by A. V. Tollestrup).—Gamma rays from the decay of π^0s photoproduced from deuterium in the bremsstrahlung beam of the CalTech synchrotron have been observed with a thallium chloride crystal total absorption gamma ray spectrometer.[1] The spectrometer has an energy resolution of about 25% with gamma ray detection efficiency of about ½. Yields at 90° (± about 12°) in the center of momentum system from both deuterium and hydrogen have been obtained for several bremsstrahlung endpoint energies from 550 to 1080 Mev, and by subtraction for several ranges of incident photon energy in this region. Results will be presented for the deuterium to hydrogen yield ratios. Some crude estimates of the cross section for π^0 photoproduction from the neutron, both singly and in conjunction with one other pion will also be given.

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] H. H. Bingham and A. B. Clegg, Phys. Rev. "Photoproduction of neutral pions from hydrogen in the energy range 700–1100 Mev" (to be published).

P8. Angular Distributions of Photoproduced Positive Pions from Hydrogen in the 600-1000 Mev Region.* F. P. DIXON AND ROBERT L. WALKER, *California Institute of Technology.*—The earlier measurements at Caltech of differential cross sections for single photoproduced positive pions from hydrogen[1] have been extended to include the entire region from 20° to 165° in the center-of-momentum system for photon energies of 600, 700, 800, 900, and 1000 Mev. The 600, 700, and 800 Mev data follow simple extrapolations of the previous data.[1] However a $\cos^3\theta$ term appears at 900 Mev and becomes very large at 1000 Mev. The angular distribution at 1000 Mev consists of a major component $(1+6\cos^2\theta-5\cos^4\theta)$ plus some interference terms which give a front-back asymmetry (larger in the forward direction). This indicates a $D_{\frac{3}{2}}$ or $F_{\frac{5}{2}}$ resonance at an energy somewhat above 1000 Mev. Such a resonance also helps explain the behavior of the π^0 photoproduction at 940 Mev[2] and is presumably that $T=\frac{1}{2}$, $J=\frac{5}{2}$ level found originally in measurements of pion-proton total cross sections.[3]

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] F. P. Dixon and R. L. Walker, Phys. Rev. Letters 1, 142 (1958).
[2] J. I. Vette, Phys. Rev. 111, 672 (1958).
[3] Cool, Piccioni, and Clark, Phys. Rev. 103, 1082 (1956); see also R. R. Wilson, Phys. Rev. 110, 1212 (1958).

P9. Study of the 'Hammer Tracks' Emitted in Nuclear Disintegrations Produced by 4.6 Bev π^- Mesons. M. BALDO-CEOLIN, *University of Padua,* AND D. J. PROWSE, *University of California, Los Angeles** (introduced by D. Stork).—A detailed study has been made of the energy and angular distributions of the fragments emitted in nuclear disintegrations and producing hammer track endings. From the momentum balance in the decay process it has been deduced that a considerable number of these tracks are caused by fragments other than Li^8. Thickness measurements have been made on a large sample of the tracks. The energy distribution of the two α particles emitted in the decay of the Li^8 fragments has been obtained and is difficult to interpret on the basis of the known energy levels in Be^8.

* Supported in part by the U. S. Atomic Energy Commission.

P10. Positive-Pion Production by Negative Pions at 260, 317, and 371 Mev.* W. A. PERKINS, J. C. CARIS, ROBERT W. KENNEY, E. A. KNAPP, AND VICTOR PEREZ-MENDEZ, *University of California, Berkeley.*—A liquid hydrogen target was bombarded by negative pions, at 260, 317, and 371 Mev, obtained from the Berkeley synchrocyclotron. π^+ mesons from the reaction $\pi^-+p\rightarrow\pi^++\pi^-+n$ were detected by using a counter telescope which selects the π^+ by its characteristic π-μ decay. With the 260-Mev beam π^+ mesons were counted at 90° in the laboratory system. At 317 and 371 Mev the differential production cross section was measured for π^+ mesons emitted at 60°, 90°, 125°, and 160° in the barycentric system. The angular distributions are nearly isotropic at both energies. Assuming a similar angular distribution at 260 Mev, a preliminary analysis of the data gives total cross sections of 0.20 ± 0.12 mb at 260 Mev; 0.75 ± 0.25 mb at 317 Mev; and 2.0 ± 0.5 mb at 371 Mev. The results of the final data analysis will be compared with those predicted by meson production in the one-meson approximation,[1,2] which is an extension of the Chew-Low theory for meson scattering.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] E. Kazes, Phys. Rev. 107, 1131 (1957).
[2] L. S. Rodberg, Phys. Rev. 106, 1090 (1957).

P11. Some Regularities Concerning the Mass Numbers of the Most Abundant Isotopes of the Fourth Group Elements. N. EFREMOV, *New York, New York.*—The mass numbers of the most abundant isotopes of the fourth group elements (C, Si, Ti, Zr, etc.) can be obtained by means of the following formulas:

C− 12= 2+8+2
Si− 28=8+2+8+2+8
Ti− 48=8+2+8+2+8+2+8+2+8
Zr− 90=8+2+8+2+8+2+8+2+8+2+8+2+8+2+8
Sn−120=8+2+8+2+8+2+8+2+8+2+8+2+8+2+8+2+8+2+8.

The mass numbers of the most abundant isotopes of other fourth group elements: Ce−140, Hf−180, Pb−208, Th−232 can be obtained in the same way. These formulas show distinct regularities in the successive series of alternating numbers (2 and 8). There are as many eights in a formula as rounded tens in the corresponding mass number. Analogous numerical regularities allow to calculate the mass numbers of the most abundant isotopes of the elements of other groups in the Periodic System.

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Second Announcement of the 1959 Southwestern Meeting

After a gap of one year, we resume the sequence of Southwestern meetings, and the host of this year's member of the sequence will be the University of Texas at Austin. The dates will be Friday and Saturday, March 6 and 7. Information as to hotels will be published in the Bulletin for the Annual Meeting.

Deadline day is Friday, January 9, and abstracts are to be sent to Karl K. Darrow, Secretary, American Physical Society, Columbia University, New York 27, N. Y. *Please be careful to mark your abstracts for the Southwestern meeting, as deadline for the Cambridge meeting arrives only a week later.*

Announcement re Cumulative Index to Bulletin for 1958

In 1956 and again in 1957, we published in the last issue of the *Bulletin* for the year a "cumulative index" of the abstracts printed during the entire year. This otherwise admirable procedure has a serious drawback: it delays the preparation and therefore the mailing of this issue. Of all the issues of the year this is the one to which delay is potentially most harmful, for it is distributed at a time when Christmas mails are already beginning to congest the postoffice, and it has to travel to the West Coast to reach most of the members to whom it is of immediate interest. Therefore we shall distribute the 1958 Cumulative Index as a separate pamphlet to be enclosed with the January 1959 issue of the Bulletin. Members who are resigning as of the end of 1958, and nonmembers who subscribed to the Bulletin in 1958 but are not renewing their subscriptions for 1959, may get it by writing to the Circulation Department, American Institute of Physics, 335 East 45th Street, New York 17, New York.

Proceedings of the American Physical Society

Minutes of the 1958 Summer Meeting on the West Coast Held at the University of British Columbia, Vancouver, Canada, August 26, 27, and 28, 1958

THE 1958 Summer Meeting on the West Coast of the American Physical Society was held in Vancouver, B.C., on Tuesday, Wednesday, and Thursday, August 26, 27, and 28. The attendance was very high and, undoubtedly, partly caused by the memory of the previous enjoyable meeting at the University of British Columbia, and also by the very large number of contributed papers on a wide variety of topics. The meeting was held at this time as part of the centenary celebration of the Province of British Columbia and the celebration of the fiftieth anniversary of the University.

There were 27 invited papers and 139 contributed papers and again only two of the latter were read by title. The total registration was 383 and the banquet attendance was 268. Professor R. T. Birge presided at the dinner and the principal speaker was Professor Denys Wilkinson on "Conferencemanship." It is no reflection on previous banquet speakers to state that this talk was probably the most entertaining and illuminating of its kind ever given before the Society. The local secretary came in for considerable criticism for not having a tape recorder handy.

The Department of Physics held an outdoor tea for the Society, two oceanographic vessels took Society members on an evening display on the sound, and a party of about 35 people were organized into a climbing expedition of Garibaldi Peak after the meeting. The ladies' program included a style show of woolens.

The local chairman was Professor G. L. Pickard, who arranged the manifold of details with meticulous precision including the very excellent and convenient on-campus housing for the members and guests.

The pleasant proceedings of the meetings were jarred on the morning of the last day by the announcement of the death of Ernest O. Lawrence. The programme was interrupted for one minute of silence and the secretary sent the following wire to Mrs. Lawrence: "The American Physical Society, assembled in Vancouver, has just learned, with profound sorrow, of the sudden death of Ernest. We send you our heartfelt sympathy for the passing of one who has made such wonderful contributions to our science that each of us has a feeling of personal loss."

W. A. Nierenberg
Local Secretary for the Pacific Coast
Department of Physics
University of California
Berkeley 4, California

Errata Pertaining to Abstracts I8, L10, and S4 of the 1958 Vancouver Bulletin (Series II, Volume 3, No. 5)

I8, by H. Wesemeyer and J. M. Daniels. In reference 1, the authors, "H. Wesemeyer and J. M. Daniels," should read "J. M. Daniels and H. Wesemeyer."

L10, by Samuel C. Lawrence, Jr. In line 6, "cling" should read "cycling." In line 21, "lattic" should read "lattice."

S4, by S. D. Elliott, Jr., and Henry A. Fairbank. In lines 11 and 12, "both transition temperatures are found to fall with increasing He^3 concentration and increasing pressure" should read "both transition temperatures are found to fall with increasing pressure for all He^3 concentrations investigated."

Minutes of the 1958 Fall Meeting of the Ohio Section of the American Physical Society, Held at Denison University, Granville, Ohio, October 17 and 18, 1958

THE regular fall meeting of the Ohio Section of the American Physical Society was held at Denison University, Granville, Ohio, on Friday and Saturday, October 17–18, 1958. Dr. Parker Lichtenstein, Dean of the College, welcomed the Ohio Section to the Denison campus, after which the programme of three invited papers relating to Low-Temperature Physics proceeded. The papers were, I. Review of Some Papers Presented at the 1958 Kamerlingh-Onnes Conference on Low Temperature Physics, by Dr. Clifford V. Heer, The Ohio State University; II. Magnetic Scattering of Neutrons at Low Temperatures, by Dr. Richard A. Erickson, The Ohio State University; III. The Death of Parity, by Dr. David F. Griffing of Miami University, Oxford, Ohio.

The Saturday morning session was devoted to five contributed papers, two of which were of general interest and need no abstracts. These two were, "Stellar Aberration and Ether Drift," by Dr. Albert B. Stewart, Antioch College, and "The Air Force Institute of Technology Subcritical Reactor," by Capt. Frank S. Beal, USAF, Department of Physics, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio. Abstracts of the three papers representing reports of research follow.

LEON E. SMITH, *Secretary*
Ohio Section of the
American Physical Society
Denison University
Granville, Ohio

Photoconductivity and Lifetime in the Presence of Long Wavelength Illumination.* J. D. NIXON AND S. MACHLUP, *Western Reserve University.*—Shockley-Read recombination statistics are extended to situations in which a nondegenerate semiconductor having a single trapping level is illuminated with low-frequency light which is absorbed only via the trapping level. The effect is to enhance the steady-state photoconductivity associated with simultaneous illumination in the fundamental absorption band. For shallow traps, the time constant for decay of photoconductivity following a pulse of the high-frequency light is shortened in the presence of the low-frequency illumination.

* Work supported by the U. S. Army Office of Ordnance Research and the U. S. Atomic Energy Commission.

Effective Molecular Collision Diameters from Pressure Broadening Effects in Infrared Band Studies.* EDGAR B. SINGLETON AND DARRELL E. BURCH, *The Ohio State University.*—A study has been undertaken to determine the effects of certain selected parameters on several infrared absorption bands. The total absorption of an entire band in the infrared is defined as the area under the curve of fractional absorption at a given frequency plotted *versus* frequency. The total absorption is found to have a functional relationship with the partial pressure of any nonabsorbing gas present in the sample under consideration. This effect, known as pressure broadening, is thought to be a function of the collison frequency of the molecules. From the data it is impossible to calculate the ratio of effective collision diameters at various values of gas pressure. These ratios will be presented together with similar ratios determined by other workers and other methods in infrared spectroscopy and atomic spectroscopy. By assuming a value for the effective radii of argon and helium, values are presented which represent the effective radii of each of the molecules studied.

* This work has been sponsored by the Geophysics Research Directorate, Air Force Cambridge Research Center, Air Research and Development Command, under contract with the Ohio State University Research Foundation.

Spin-Lattice Relaxation Times in Liquids.* F. D. ADAMS AND A. A. SILVIDI, *Kent State University.*—Proton spin-lattice relaxation times T_1 are being measured in liquids using a NMR spectrometer. The direct method of measurement is being used. Parameters are: rf frequency-25 Mc, field H-5870 gauss, modulation amplitude −1 gauss, and modulation frequency-260 cps. For water (dissolved oxygen-0.0057 cc/g standard pressure and temperature 26°C) the measured valve of T_1 is 2.8 ± 0.1 sec. For diethyl ether T_1 is 3.5 ± 0.3 sec. These measurements agree well with those made by Bloembergen, Purcell, and Pound[1]. Spin-lattice relaxation times are being measured for other liquids.

* Partially supported by the U. S. Air Force through the Air Force Office of Scientific Research under contract.

[1] Bloembergen, Purcell, and Pound, Phys. Rev. 73, 679 (1948).

MEETINGS AND DEADLINES FOR THE SEASON 1958–1959

Place	*Meeting dates*	*Deadline date*
Los Angeles*	December 29–31	past
New York	January 28–31, 1959	November 14
Austin, Texas	March 6–7	January 9
Cambridge, Massachusetts	March 30, 31, April 1	January 16
Washington, D. C.	April 30, May 1–2	February 20
Milwaukee, Wisconsin	June 18–20	to be decided
Hawaii	August 27–29	to be decided

* Abstracts for the Los Angeles meeting are to be sent to W. A. NIERENBERG, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date.

Abstracts for the other meetings listed above are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. Take note that abstracts mailed the day before deadline day often fail to arrive in time: the last postal delivery of the day usually comes to our office before 2 P.M. Allow at least two days for abstracts sent by airmail from points east of the Mississippi, and longer for those sent from farther west. Abstracts postmarked (at the point of dispatch) on deadline day are instantly rejected, and telegrams heralding their arrival are fruitless except in revenue to the telegraph company. *The privilege of contributing papers to meetings of the American Physical Society is restricted to the members of the Society and to nonmembers whose papers are sponsored by members.*

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BULLETIN

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Cumulative Author Index

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In 1956 and again in 1957, we published in the last issue of the *Bulletin* for the year a "cumulative index" of the abstracts printed during the entire year. This otherwise admirable procedure has a serious drawback: it delays the preparation and therefore the mailing of that issue. Of all the issues of the year this is the one to which delay is potentially most harmful, for it is distributed at a time when Christmas mails are already beginning to congest the postoffice, and it has to travel to the West Coast to reach most of the members to whom it is of immediate interest. Therefore the 1958 Cumulative Index is distributed as a supplement to this January, 1959, issue of the Bulletin. Members who resigned as of the end of 1958, and nonmembers who subscribed to the Bulletin in 1958 but have not renewed their subscriptions for 1959, may get it by writing to the Circulation Department, American Institute of Physics, 335 East 45th Street, New York 17, New York.

Cumulative Author Index of Abstracts Appearing in Volume 3, 1958, of the Bulletin of the American Physical Society

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